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A New Copernican Era

About four centuries ago a volume was published which changed the trend of thought concerning the universe and set the pattern of thinking which has continued from that day to this. The title of the volume is *De Revolutionibus Coelestium* and its author was Nicholas Copernicus. It marked the beginning of the Copernican era. The central thought of this epoch-making work is epitomized in the legend inscribed on the monument erected in honor of Copernicus in the University Church of St. Ann in Krakow:

The Sun he bade to stop and at his bidding the
Earth began to spin.

Many minds very reluctantly accepted the implication of this work. According to it the earth was necessarily removed from its hitherto exalted position as the center of the universe and given rank coördinate with the other planets which, like it, revolved around the sun. It was not easy to have the earth thus deposed, because, with the lessening in importance of the earth, man himself might suffer a similar change. But evidence in favor of the idea was cumulative and the truth prevailed.

However, the Copernican earth was still a large body. Few persons, relatively speaking, saw more than a small portion of it, and no one saw all of it. Near the close of the nineteenth century an imaginary journey around the world in eighty days was considered such a feat as to justify a book of more than three hundred pages concerning it. Volumes were written, startling in their revelation of customs and cultures indigenous to one part of the earth yet utterly foreign to another part. In this frame of mind we came to the outbreak of the war.

Now, because of the exigencies of war, millions of men and women are moving constantly from one part of the earth to parts 180 degrees away. There are no places more remote. Daily we hear voices from places, which until recently seemed fictitious, describing events happening there and we are cheered or depressed by them because they seem so near at hand. These are indications of the figuratively lessening dimensions of the earth.

We are living in a new Copernican era.

JANUARY 1, 1945.

Personal Equation in Astronomy*

By RAYNOR L. DUNCOMBE

Introduction

In view of the great mass of literature which has been written about personal equation in astronomy, a history of this subject must be able to justify its appearance at this time. In the eyes of most astronomers, personal equation seems largely a problem of the past, which through the use of improved observational methods, has been almost entirely eliminated. In its early history this phenomenon was inextricably bound up with meridian transit work, and the successful efforts to reduce and control it in this field have led many people to ignore its still significant presence in other branches of astronomy.

The two most complete accounts of the history of personal equation have been written by psychologists, E. C. Sanford[29] and E. G. Boring,[80] but they both break off near the end of the last century. Again, these men have written of personal equation essentially from the point of view of its importance to the psychology of reaction time, and not from the standpoint of the astronomer. It has thus been deemed justifiable to review the early history of personal equation as viewed in the light of more recent psychological thought, and to continue forward to the present time the account of the research in meridan transit work and other fields of astronomy done on this question.

No attempt has been made to give a thorough review of the early history, since this has already been well presented by Sanford and Boring. The mere outline of this early period given here has been drawn largely from their accounts, augmented by a number of additions from other sources.

SECTION I

The Bradley Method and Personal Equation

Any history of personal equation in astronomy must necessarily begin with an account of David Kinnebrook at Greenwich in 1795. In the Greenwich *Astronomical Observations,* Volume 3,[1] Maskelyne, the astronomer royal, entered the following statement below the observations for July 31, 1795:

"My assistant, Mr. David Kinnebrook, having at this time unfortunately commenced a vicious way of observing the times of transits too late, it will be necessary to make an allowance for those errors where his observations . . . are intermixed with mine . . ." Further on in the same volume, Maskelyne continues:

*Note: The references in this paper will be given in chronological order at the end of the final installment.

"I think it necessary to mention that my assistant, Mr. David Kinnebrook . . . began from the beginning of August last, to set them [the transits] down half a second of time later than he should do, according to my observations; and in January of the succeeding year, 1796, he increased his error to 8/10 of a second. As he had unfortunately continued a considerable time in this error before I noticed it, and did not seem to me likely ever to get over it, and return to a right method of observing, therefore, though with great reluctance . . . I parted with him." Thus an obscure assistant at Greenwich Observatory was ushered out of a job and into a unique place in astronomical history; the first recorded instance of personal equation.

The method of observing used at this time was introduced by Bradley. In the field of the transit instrument was a series of evenly spaced vertical wires. A clock beating seconds was placed near the instrument and as a star crossed the field the observer noted the proportional distance of the star from the wire at the two clock beats immediately preceding and following the transit across each wire. The transits for each wire were put down to $0^s.1$, and while Maskelyne admitted that the time for each wire might be in error by $0^s.2$, he assumed that the mean of the wires in the field would be accurate to $0^s.1$.

With this assumed accuracy it can readily be seen why Kinnebrook's error of $0^s.8$ could not be tolerated. In using the Bradley method, Maskelyne cautioned, "If we are not quick in fixing the place of the star at the [clock] beat, we shall be apt to assign to it too backward a place in the telescope, and consequently to reckon on the time of the transit too great, as my late assistant did." With this explanation, Maskelyne dismissed the question of discrepancies between the results of different obervers.

The question of personal errors remained dormant from the time of Kinnebrook's dismissal until 1816 when von Lindenau mentioned the incident in a history of the Greenwich Observatory. Bessel, the astronomer at Königsberg, took note of this and at once became interested in the problem. It occurred to Bessel that once Kinnebrook had been informed of his "error," he must have tried to correct for it. His failure to do so convinced Bessel that it must have been involuntary. With this thought in mind Bessel set out to find his own personal equation.

In 1820 he compared himself with Walbeck at Königsberg. Two groups of five stars each were chosen and both men observed these groups alternately for five nights. The results revealed that Bessel observed, on the average, $1^s.041$ earlier than Walbeck. It was fortunate for astronomy that this difference was large for it urged Bessel on to further study of personal equation. When published in the *Königsberg Observations* for 1822 it aroused a great deal of discussion and introduced a distrust of the accuracy of the Bradley method that led astronomers to seek a more accurate method of observation.

Bessel made other determinations of personal equation during the next decade and the series with Struve is especially notable. In four comparisons between 1821 and 1834 the equation Bessel minus Struve was —0^s.799, —1^s.021, —0^s.891, and —0^s.770. Bessel recognized the variability of this personal equation, but, in accord with other astronomers of the time, agreed that greater accuracy could be achieved if transit observations were corrected for the differences between observers. During this same period Bessel found that his personal equation with respect to Argelander for transit work was —1^s.223, whereas for occultations the same relation was only —0^s.222. Bessel also found that by using a clock beating half-seconds, he observed transits about 0^s.05 later than usual.

Other observatories followed Bessel's example and it seems certain that no longitude determination work has been done since that time that does not take personal equation into account. Robinson,[13] at the Armagh Observatory in Ireland in 1830, made a study of personal equation in observations of the first and second limbs of the sun and moon. At Altona, in 1833 and later, the equations Nehus — Wolfers = +0^s.73, and Peterson — Mädler = +0^s.52 were determined. In publishing the longitudes of Göttingen, Marburg, and Mannheim, in 1838, Gerling corrected the observations for the relative difference between himself and the other observers. Also in 1838, Airy began publishing in the *Greenwich Observations* the personal equations of his transit observers as determined from the clock corrections. This has furnished two long series of comparisons; first Main — Rogerson averaging —0^s.7, and Main — Henry averaging about —0^s.06.

In 1845 Lt. Maury[5] wrote of a test made for personal equation at the U.S. Naval Observatory which "consisted in casting, by a proper adjustment of the eyepiece, a sharp image of the sun and wires at the time of transit, upon a screen placed at a little distance from the telescope, and to require each of the four officers to observe and record in silence the transit of the Sun." This method avoids the necessity of dealing with the clock correction, as did the binocular eyepiece introduced at Greenwich in 1852.

These determinations and others in this period revealed that the personal equation was more variable than the instrumental constants and thus did not lend itself readily to the system of corrections applied to the constants. Faced with this problem, astronomers began looking for some method of transit observation that would diminish and control the personal equation.

It should be noted here that the personal equations found in the early part of this period are not definitive because of the method used in correcting instrumental constants. It was the custom at that time to adjust the transit instrument frequently so that the collimation, level, and azimuth factors equalled zero. In Volume 3 of the Greenwich *Astronomical Observations,* Maskelyne time and again notes with some

amazement that he has found the collimation factor appreciably large after having just set it to zero several weeks before. J. M. Gilliss,[6] writing about his observations at Washington from 1838 to 1842 states ". . . it was not until the latter part of 1840 I became aware that the exact state of astronomical science demanded more than a simple record of the transits, after the errors of the instrument had been rectified."

Airy, while at Cambridge, seems to have been the first to realize the inconsistency of this method. He felt that the instrumental constants varied more than was suspected at the time and that even when the constants were set to zero, the instrument would "drift" off in a short time. Airy, therefore, advocated leaving the instrument uncorrected, and correcting the individual star reductions for the instrumental errors in much the same manner as it is done in transit circle work today. Airy's method of treating the instrumental constants did not acquire wide-spread use during that period, so that, while these early personal equations are purely relative, if the two men being compared worked on different nights their personal difference may also be influenced by changes in the constants.

Bessel, after establishing the fact that personal equation did exist in transit work, turned his attention to the cause of this difference. In the first half of the nineteenth century it was generally held that the time required for nervous impulse transmission was nil. Maskelyne had not recognized Kinnebrook's error as being personal equation and had blamed it on a misuse of the Bradley method. Bessel,[2] aware that this difference was personal, ascribed it to a psycho-physiological cause.

"If it is assumed that impressions on the eye and ear cannot be compared with each other in an instant, and that two observers use different times for carrying over the one impression upon the other, a difference originates; and there is a still greater difference if one goes over from seeing to hearing, and the other from hearing to seeing. That different kinds of observation are able to alter this difference need not seem strange, if one assumes as probable that an impression on one of two senses alone will be perceived either quite or nearly in the same instant that it happens, and that only the entrance of a second impression produces a disturbance which varies according to the differing nature of the latter." As the pioneer hypothesis of personal equation, Bessel's analysis shows keen insight, and he gives a hint here of the later widely-accepted psychological theory of prior entry.

With the Bradley method, if a star is approaching the micrometer wire and the observer goes from seeing to hearing, the observed transit time will be too great. Again, if the observer goes from hearing to seeing, the transit time will be too small. According to this explanation, Bessel and Maskelyne went from hearing to seeing, while Argelander and Struve went from seeing to hearing. It was only at this time that astronomers began to realize that the $0^s.8$ difference between Maskelyne

and Kinnebrook might have been caused in part by Maskelyne's tendency to observe transits too early. This seems to be borne out by the discovery that Maskelyne observed transits $0^s.27$, $0^s.18$, and $0^s.14$ earlier than three of his other assistants.[41] H. P. Hollis[97] has even gone so far as to suggest that Maskelyne's perception of sound was impeded by old age and that therefore, he, rather than Kinnebrook, was responsible for the $0^s.8$ relative equation. In this connection it may be significant that Newcomb[19] found Maskelyne's catalogue to be systematically $0^s.128$ too small in right ascension.

Another cause for personal equation was suggested in 1830 by the astronomer Nicolai.[4] "In my opinion it can scarcely have its basis in any other causes than that a difference exists in different individuals for mental reflexes from external impressions of the eye and of the ear. Thus one comes to believe that in one individual the mental reflex from the eye, for example, occurs earlier than the mental reflex from the ear . . ." This idea was not received as favorably as Bessel's, but is indicative of the thought that was being given to the question of personal equation.

Thus, in the first half of the nineteenth century, the existence and variability of personal equation were established. And as the 1850's approached, astronomers turned their attention more and more toward the task of further controlling and diminishing this troublesome personal error.

SECTION II

The Key-and-Chronograph Method of Observing

The second period in the history of personal equation in astronomy begins about 1850 with the introduction of the key-and-chronograph method of observing meridian transits. It should not be inferred that the Bradley method was discarded at this time. Rather, it was continued in use for many years in conjunction with the chronograph method.

It had been realized from Bessel's analysis of the cause of personal error in the Bradley method, that if the observer were given one operation instead of two, this error might be diminished. In 1828, O. P. Repsold suggested a method wherein as a star crossed each wire of the transit micrometer, the observer pressed a key, thereby making a mark on an evenly moving tape. His device did not have a constant rate of motion, however, and he died before being able to perfect it. In 1843, Arago[10] arranged to have the observer at the telescope make a sharp audible signal at the instant the star was bisected by the micrometer wire. An assistant, standing at the clock, estimated the time of this sound between the two adjacent clock beats, and set down the transit time. Thus, each man had but one stimulus to respond to. Arago found that this greatly reduced the personal equation and as an improvement he arranged the second hand of the chronometer to make a mark on the

dial when a trigger, held by the observer, was pulled. A photographic method suitable for sun transits was described by Faye[7] in 1849. Instantaneous exposures were made at regular intervals of the sun's limb and the micrometer wires, in this way eliminating the observer entirely. The method could not be used for star transits, however, due to lack of sufficient light, and so was not adopted.

The eventual development of the chronograph was due largely to a combination of the Morse printer and a clock wired to operate an electric circuit at each beat. Bache and Walker of the U. S. Coast and Geodetic Survey have been given most of the credit for developing the chronograph as we know it today.[12] While Bache undoubtedly coördinated and encouraged this work in the middle of the nineteenth century, the inventive ability of Dr. John Locke[8] of Cincinnati was responsible for much of its design.

Up to this time, clocks which transmitted their beats over electrical circuits had been devised by Steinheil, Bain, and Wheatstone, but they made no record and could only operate a Morse sounder or keep a distant clock in synchronism.[106] In longitude work these transmitting clocks were a decided advancement since the time at the primary station could be sent by wire to the secondary stations. With these clocks, however, if the transmitting line was broken even momentarily, the observers at the secondary longitude stations could not identify the beat being transmitted from the primary station when the circuit was resumed.

Locke's design of a chronograph with rotating drum and moving pen carriage was a partial answer to this problem. His second contribution was a transmitting clock which identified the beginning of each hour and minute by the omission of certain beats. With this chronograph, the signals from the key held by the observer were made as interruptions in the record of the clock beats. In using this apparatus in longitude work, the clock at the primary station would transmit its beats by wire to chronographs in each of the secondary stations. If the circuit was interrupted, when transmission was resumed the seconds being recorded at the secondary longitude stations could be identified by the omission of certain clock beats. A clock and chronograph designed by Locke were installed at the U.S. Naval Observatory in 1849. In 1854 a somewhat similar chronograph designed by Bond[9] was put in use at the Greenwich Observatory. The fundamental design of Locke's chronograph has remained unchanged since 1850, although later developments have produced the kymograph and various printing and photographic chronographs.

The introduction of the key-and-chronograph method of recording meridian transits made it possible to determine reliable absolute personal equations. It must be remembered that the personal equations prior to this time are mainly relative, that is, most of them were determined by comparing one observer's results with those of another observer. This

method did not reveal the difference between each observer and the true time of transit.

F. Kaiser of Leiden proposed a scheme in 1851 for the determination of the absolute personal equation involved in the Bradley method. In addition to the standard clock he used another clock which beat at a slightly different rate. Actuated by clockwork, an artificial star was moved across the telescope field. At the instant of coincidence of the star and the micrometer wire, the pendulum of the vernier clock was automatically released. An assistant then counted the beats until the two clocks coincided and from the known rates of the clocks, the true time of the transit could be derived. This, compared with the observed time of transit, gave the absolute personal equation. In 1858 Hartmann described a machine for finding the absolute personal equation with the Bradley method, but the device was too complicated to produce consistent results.

With the advent of the chronograph, more trustworthy machines for determining absolute personal equation were developed. Plantamour, Hirsch, Kaiser, and Eastman[21] are among those who devised machines in the 1860's and '70's. These early machines, generally speaking, consisted of a simulated star, moved horizontally by clockwork and focused on a translucent surface which was marked with several vertical lines in representation of transit micrometer wires. This simulated micrometer field was viewed through a short tube or with a low-power eyepiece. As the artificial star moved across the field, a pointer on the carriage moved over contacts which corresponded to the lines in the field. These contacts were recorded on a chronograph, as well as the contacts made by the observing key. The absolute personal equations found in this manner were applied to the star transit times observed with the meridian telescope.[34] A more complete description of these early machines will be found in a paper written by John L. E. Dreyer[22] in 1876.

After a period of experimentation, however, astronomers became dissatisfied with this procedure. It was deemed more accurate to determine the absolute personal equation with the same micrometer with which the real star transits were observed. In 1889 Wislicenus[31] experimented with a measuring device which was mounted inside the transit telescope. A concave mirror set inside the objective converged the rays from the field lamp, thus forming a spot which moved over the field as the eyepiece was moved. The eyepiece was driven by clockwork and contacts on the eyepiece slide were recorded on a chronograph. One advantage claimed was that the absolute personal equation could be determined in all positions of the instrument. The system of electrical contacts did not function properly at different declinations, however, thus invalidating the results.

The method finally developed for measuring personal equation with the transit telescope micrometer was to place the machine in one of the

mark houses of the transit instrument and observe the simulated star as it crossed the field of the telescope. This use of transit telescope and personal equation machine in conjunction has been continued through the key-and-chronograph period up to the present time, at some observatories, for investigations in connection with the Repsold, or traveling-wire transit micrometer.

With the development of the chronograph and of reliable personal equation machines, it might seem that the problem of personal error in meridian transit astronomy had been solved, but experimentation in the latter half of the nineteenth century and early twentieth century proved otherwise. A plethora of material was written on the question during this period, and virtually any observational catalogue of the time provides an interesting discussion of personal equation.

When the chronograph was brought into use in astronomy no exact method of observing meridian transits was prescribed. As a result, although the difference was not recognized at first, two distinctly different methods developed; like Topsy, they just grew. Gould and Gill seem to have been the first astronomers to note that two methods existed. Gill[24] in discussing the observed positions of Mars comparison stars in 1878 found systematic differences in the results from various observatories. Seeking a cause for these differences he found that there were two distinct habits in recording transits with a chronograph. He noted that the majority of observers anticipated the transit so that the sound of the key tap coincided with the transit. Gould[18] pointed out, in *Transatlantic Longitude*, that this method introduced an error which varied with declination. He urged that all observers should not tap the key until the star was seen to be bisected. This, he said, would eliminate the variation introduced by changes in declination.

Newcomb[39] classified these two methods as follows: "In method A, which I believe to be the most common, the observer anticipates the passage of the star, so as to have his signal completed at the exact moment of crossing [the wire], much as if he were shooting at a [flying] bird. In the other method, which I shall call B, the observer waits until he actually sees the star on the thread, and then commences the nisus which terminates in the signal." Newcomb states that he prefers method A, which amounts essentially to this; that the observer fixes by habit a certain spatial interval such that when the star is this distance from the wire, prior to crossing, and the observer starts his reaction, the sound of the signal coincides with the bisection of the star by the wire. Assume that the observer chooses the size of this spatial interval while observing stars of 30° declination. His transit times for faster moving stars (closer to the equator) will then be late, and for slower stars (closer to the pole) will be early. This error, which varies as the secant of the declination, is a fault of method A, and is eliminated by method B.

Confirmation of this personal error with declination came from many

sources. C. H. Hins,[72] in a discussion of zone work at Amsterdam involving three observers, found that two observers registered stars of high declination too soon, and stars of low declination too late, relative to the mean of a zone. This change in the personal equation between declinations 10° and 50° was from 0^s.011 to 0^s.058 for one observer, and from 0".014 to 0".071 for the other. The third observer had no change in personal equation with declination. Hins found that the first two observers used method A, while the third used method B. In the 1903-1911 program of the nine-inch transit circle at Washington,[70] the final corrections deduced for this personal error were Littell —0^s.134 secant declination, and Morgan —0^s.032 secant declination. A similar error varying with declination was also found in the 1913-1926 program of this instrument.[89] Other astronomers, however, using method B, found no change in personal equation with declination. M. Gonnessiat[36] of the Lyons Observatory, for example, conducted tests for this phenomenon in 1890-91, but could find no evidence of a declination equation.

In his discussion of the Mars comparison stars, Gill also suggests the idea of a variation of personal equation with magnitude in method A. An observer who anticipates, Gill states, ". . . will be nearly certain to press [the key] too soon for very bright and too late for very faint stars, because the larger disk and the rings of a bright star will make it appear closer to the web than the small sharp disk of a faint star at the same angular distance from the web." He implies that this magnitude error would not occur with method B, but Newcomb disagrees with Gill on this point.

Numerous instances of this magnitude error have been published. Bakhuyzen's experiments at Leiden in 1878 confirmed that faint stars were observed roughly 0^s.05 later than bright ones.[22] In a comparison of photographic plates with the Cambridge Catalogue of 1875, Turner[43] found that 8.0 magnitude stars were observed 0^s.10 later than 5.0 magnitude stars. Hinks[40] found a magnitude equation in the Cambridge Zone Catalogue of 1896, and in the Berlin zone work of the same year, an equation of —0^s.007 per magnitude that increased linearly with brightness was noted. In 1891 Christie[33] described a method of using screens over the objective of the Greenwich transit circle, stating that screened stars were observed later than unscreened stars. Tucker,[45] in discussing the 1893-96 program at the Lick Observatory, found that each faint star apparently transited 0^s.009 later than a star one magnitude brighter. In 1900 a similar magnitude effect was found in the work of the six-inch and nine-inch transit circles at Washington. One of the most thorough determinations of magnitude equation for correcting an observational program has been made by Küstner;[60] the investigation also apparently being the first to include the color effect of the stars.

It must be assumed that Newcomb was correct in believing that the magnitude error would be present in both methods A and B, since no

published results have been found to indicate that method B eliminated this personal error. In fact, Lewis Boss,[48] experimenting at the Dudley Observatory about 1900, found that he had a magnitude equation of the same order with either method A or B.

Astronomers also discovered that in key-and-chronograph observations, whether method A or B, the direction of the star's motion introduced a change in the personal equation. C. Wolf at Paris, and Wagner at Pulkowa, noted this phenomenon about 1870, and in later transit circle observational programs many references are made to it. In an 1875-77 program of differential longitudes in India, Captain Campbell[23] found this same effect and called it ". . . a novel feature of Personal Equation." His north — south difference amounted to $+0^s.077$.

This personal error due to the direction of motion of the stars is termed a head north minus head south difference since as the instrument is changed from a setting south of the zenith, to one to the north, the observer has to change his position from head north to head south. In the 1893-96 program at the Lick Observatory, Tucker[45] found a north minus south difference in right ascension of $+0^s.030$ and in declination of $-0''.05$. Again, in the six-inch transit circle program of 1900-01, Updegraff[54] noted a head north minus head south value in right ascension of $+0^s.028$ and in declination of $+0''.41$. Gill seems to have been the first astronomer to analyze this personal equation as a bisection error. As early as 1864, C. Wolf had discovered that he was unable to judge the middle point between two dots, but at the time this was believed due to some physiological fault of his eye. It soon became evident, however, that other observers had bisection errors also, probably due mainly to faulty judgment.

The remedy for this personal error was the reversing prism eyepiece. A reversing eyepiece was used experimentally in 1884 at Greenwich. On fine nights two clock stars were observed with reversed motion, but all the other observing was done with a non-reversing eyepiece. The reversing eyepiece has been used occasionally at both Greenwich and Cape since that time. In 1910 a reversing eyepiece was added to the six-inch transit circle at Washington, and a few years later, to the nine-inch. Since that time it has been the regular practice at Washington to make half of each observation with the prism direct and the other half with it reversed.

That an observer's personal equation for the sun and moon might differ from that for stars was first indicated by Robinson,[13] of the Armagh Observatory, in 1830. He found the probable error of an observation, by the Bradley method, of the first limb of the sun to be larger than that for the second limb. He later concluded that this was due to personal equation, and that the cause was irradiation, since the error could be reduced by strong field illumination. Dunkin,[20] in discussing the Greenwich sun observations from 1864 to 1873, noted

that each observer had a decided personality, differing for each limb of the sun. Dunkin[17] said this difference in personality for each limb also applied to observations of the moon. Stroobant,[46] in experiments with a personal equation machine in 1891, found his personal equation was larger for the first limb of discs representing the moon, Jupiter, Mars, Saturn, and Uranus, than it was for the second limb. A reversing prism eyepiece was not used in any of the above observations, so the bisection error is present. Later work at Washington, where a reversing eyepiece was used, gave smaller differences between limbs one and two, but the personality for the sun was still found to differ from that for the stars.

Scale error, which had been present in eye-and-ear observations, appeared also in the key-and-chronograph method. This is an error in estimating fractions of an interval, with the result that the fractions do not appear with equal frequency. Scale error arises from improper judgment on the part of the observer and may cause a systematic error in transit observations. In the Bradley method the scale error affects the observer's estimate of the distance of the star from the micrometer wire at each clock beat. With the key-and-chronograph method, the scale error enters in reading up the chronograph sheets.[100] It should be noted that in taking the mean results of several observers, their scale errors will not necessarily cancel out.[75]

Aside from the variations of personal equation with the object, (sun or star), and with the speed, direction of motion, and magnitude of the stars, experimenters in the latter part of the nineteenth century asserted that the illumination of the reticle, the position of the observer, and the type of observing key all exerted some influence. Improved field lighting alleviated the first mentioned effect, and the last two still lack confirmation. One of the most complete discussions and mathematical analyses of the types of personal equation evident in an observational program is given by H. R. Morgan in *U. S. Naval Observatory Publications,* Volume XIII, 1933, which yields further information on the personal differences mentioned above.

The key-and-chronograph method of observing reduced the personal equation and the probable error incident to the Bradley method, but it increased the accuracy of observations to the point where other types of personal error became evident. As it affected the true transit time, the absolute personal equation with method B measured about $0^s.1$, while with method A it was even less. But, as Campos Rodrigues,[50] of the Royal Observatory at Lisbon, pointed out in 1902, method B was best for observing since it gave the smallest probable error in the means of clock corrections. He stated that beginners usually tried method A because it made their personal equations small, but that this anticipation method increased their probable errors.

Despite this disadvantage, however, the majority of observers seem to have continued using method A in this period. The examples of Dun-

kin, Ellis, and Henry at Greenwich illustrate the decrease in the probable error of the chronograph method over the Bradley method.[29]

	Henry	Dunkin	Ellis
Eye and Ear	±0ˢ112	±0ˢ062	±0ˢ069
Chronograph	±0ˢ058	±0ˢ048	±0ˢ053

The discovery of so many additional forms of personal equation at this time led astronomers to believe that there might be many more as yet undiscovered, and made it seem impractical, if not impossible, to correct for so many variants. At a time when meridian transit astronomers were trying to increase the accuracy of their observations, the discovery of so many "unknown" equations cast some doubt on the whole structure of fundamental astronomy.

In 1828 Airy[3] had stated the main fault of the Bradley method as follows: ". . . I wish to express the feeling, of which the observer is sometimes painfully conscious, that he cannot, by any effort, bring the eye and ear to act together in the manner which is necessary for observing a transit." Now Newcomb expressed the observer's dissatisfaction with the chronograph method by pointing out that when the atmosphere was at all disturbed the stars seemed to jump over each wire, instead of crossing them at an even rate. It became more and more evident that a still better method of observing star transits was needed, and at the end of the nineteenth century, in response to this need, the new Repsold traveling-wire micrometer was being perfected.

It might be noted here that after 1880 very little theorizing was done by astronomers as to the fundamental causes of the various types of personal error. The astronomers continued to measure and correct for these quantities, but those few astronomers who continued trying to unlock the riddle of why personal error existed were regarded as mere amateurs by the sage professionals. These professional astronomers realized that the question of the psycho-physiological basis for personal error had been taken out of their hands. For in the latter half of the nineteenth century, a new science had come into existence; the science of experimental psychology.

(To be continued)

Distances of Planets from the Sun and of Satellites from their Primaries in the Satellite Systems of Jupiter, Saturn, and Uranus

By D. E. RICHARDSON*

ABSTRACT

It is found that the mean distances of planets from the sun and of satellites from their primaries in the satellite systems of Jupiter, Saturn, and Uranus are in obeisance to a common law of variation with respect to planet (or satellite) ordinal number. The principal variation of distance with respect to ordinal number is exponential and found to be given by $(1.728)^n$. This principal variation is modified by a second variation, individual values of which, for a given system, equal the lengths of radii vectors of an ellipse corresponding to polar angles $(4\pi/13)n$. While each system has its own characteristic distribution ellipse, the various ellipses have certain properties in common. With the exception of a few orbital bodies that subtend unusually small solid angles at the centers of their respective systems, the probable error of computed distances is 0.20 of one per cent, the greatest single error being 0.764 of one per cent.

The purpose of this paper is to demonstrate that a common law of variation exists for the mean distances of planets from the sun and of satellites from their primaries in the satellite systems of Jupiter, Saturn, and Uranus. This common law of variation is with respect to planet (or satellite) ordinal number.[1]

When mean sun-to-planet distances are plotted against planet ordinal numbers, using rectangular semi-logarithmic coördinates, the graph of Figure 1 is obtained. The general trend of the plotted points is given by the straight line of this figure. This line has the equation

$$\log_{10} D_n = \log_{10} D_0 + n \log_{10} \tau \qquad (1)$$

where $\log_{10} D_0$ is its intercept with the vertical axis and $\log_{10} \tau$ its slope. Equation (1) corresponds to the simple exponential variation

$$D_n = D_0 \tau^n \qquad (2)$$

The straight line, as shown, has values of $\log_{10} D_0$ and of $\log_{10} \tau$ that

*Armour Research Foundation, affiliated with Illinois Institute of Technology, Chicago, Illinois.

[1] The ordinal number of a planet (or satellite) denotes the order of its remoteness from the central body of the system. In the present paper the maximum values of ordinal numbers used are: Solar system 10, Jupiter's system 10, Saturn's system 10, Uranus' system 5.

were determined by the method of least squares from ten observation equations [of the form of equation (1)], using known (observed) values of $\log_{10} D_n$ for the various planets. The observation equations used are shown in Table I. Their solution yields $\log_{10} D_o = -0.670341$ and $\log_{10} \tau = 0.23325$. The corresponding value of τ is 1.711.

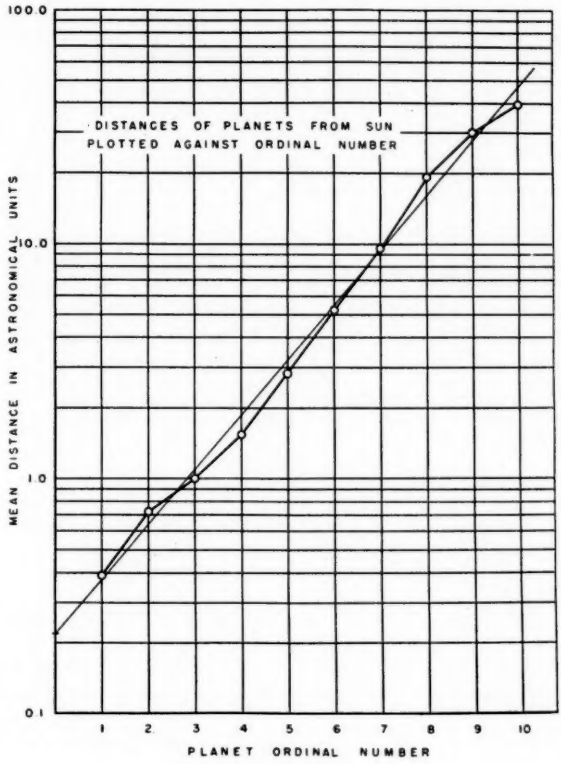

FIGURE 1
SEMI-LOGARITHMIC PLOT OF L_n AGAINST n.

The plotted points of Figure 1 oscillate in a regular manner above and below the straight line of simple exponential variation. This suggests representing values of D_n by an equation of the form

$$D_n = D(\kappa n) \cdot \tau^n \qquad (3)$$

in which $D(\kappa n)$ is an oscillatory function of κn, κ being a constant. Since $D(\kappa n)$ is considered oscillatory, it is reasonable to suppose that a polar coördinate plot of D_n/τ^n values against values of κn may prove enlightening. A reasonable (tentative) value of κ appears to be $4\pi/13$.

TABLE I

OBSERVATION EQUATIONS USED FOR DETERMINING THE GENERAL TREND OF PLOTTED POINTS IN FIGURE 1

	$\log_{10} D_0 + n \log_{10} \tau = \log_{10} D_n$*
1	$\log_{10} D_0 + 1 \log_{10} \tau = 9.5878221 - 10$
2	$\log_{10} D_0 + 2 \log_{10} \tau = 9.8593371 - 10$
3	$\log_{10} D_0 + 3 \log_{10} \tau = 0.0000000$
4	$\log_{10} D_0 + 4 \log_{10} \tau = 0.1828961$
5	$\log_{10} D_0 + 5 \log_{10} \tau = 0.4420562$
6	$\log_{10} D_0 + 6 \log_{10} \tau = 0.7162374$
7	$\log_{10} D_0 + 7 \log_{10} \tau = 0.9794957$
8	$\log_{10} D_0 + 8 \log_{10} \tau = 1.2830971$
9	$\log_{10} D_0 + 9 \log_{10} \tau = 1.4781431$
10	$\log_{10} D_0 + 10 \log_{10} \tau = 1.5961288$

*Determined from values of D_n taken from "Astronomical Constants" in the *American Ephemeris and Nautical Almanac.*

This follows from observing in Figure 1 that the period of oscillation approximates $n = 6.5$, so that the value of $(4\pi/13)n$ for $n = 6.5$ becomes 2π, which corresponds to one natural cycle in a polar plot. Using known values of D_n and the "most probable" value of τ obtained by the method of least squares, values of D_n/τ^n are plotted as radii vectores against values of $(4\pi/13)n$ as polar angles in Figure 2.

A smooth curve, having the form of a spiral, connects the plotted points in Figure 2. Inspection suggests that an increase in the value

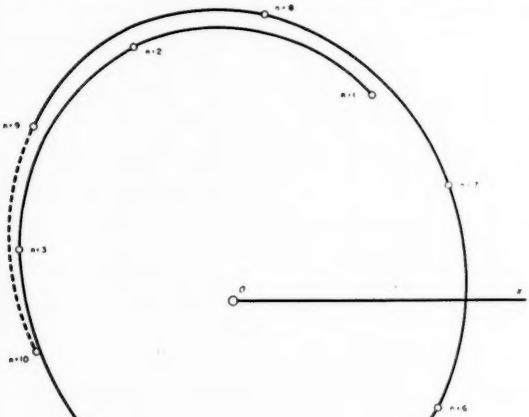

FIGURE 2

VALUES OF D_n/τ^n FOR PLANETS OF THE SOLAR SYSTEM PLOTTED AGAINST $(4\pi/13)n$.

of τ may transform the spiral into a closed figure. This has been found to be true, and for $\tau = 1.728$ the figure approximates a true ellipse as is shown in Figure 3 where values of $D_n/(1.728)^n$ are plotted against $(4\pi/13)n$. The general agreement between the plotted points and corresponding radii vectores of the ellipse (in Figure 3) is good except

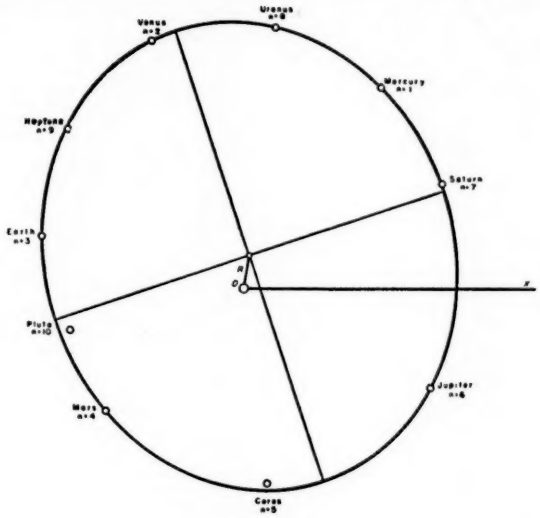

FIGURE 3

VALUES OF $D_n/(1.728)^n$ FOR PLANETS OF THE SOLAR SYSTEM PLOTTED AGAINST $(4\pi/13)n$.

in the case of Ceres and Pluto.[2] It should be remarked that no appreciably better value for κ than $4\pi/13$ has been found.

The foregoing analysis leads to the conclusion that, to a good approximation, *the mean distances of planets from the sun are given by the equation*

$$D_n = D\,[(4\pi/13)\,n] \cdot (1.728)^n \qquad (4)$$

where n *is planet ordinal number and the values of* $D\,[(4\pi/13)n]$ *are the radii vectores of an ellipse, having polar angles* $(4\pi/13)n$. This ellipse will be called the "distribution ellipse for the planets of the solar system." The notation of equation (4) can be simplified by writing ρ_n for the values of $D\,[(4\pi/13)n]$ corresponding to integral values of n; that is, we may regard the ρ_n to be the particular radii vectores of $D\,[(4\pi/13)n]$ that correspond to the various planet ordinal numbers. By this change, equation (4) becomes

$$D_n = \rho_n\,(1.728)^n \qquad (4)'$$

[2] Ceres and Pluto each subtend unusually small solid angles at the system center. This point is discussed near the end of this paper, paragraph 7.

The ellipse of Figure 3, with center displaced a short distance from the pole of the coördinate system, is of the general form shown in Figure 4. The corresponding general equation in terms of the parameters of Figure 4 is

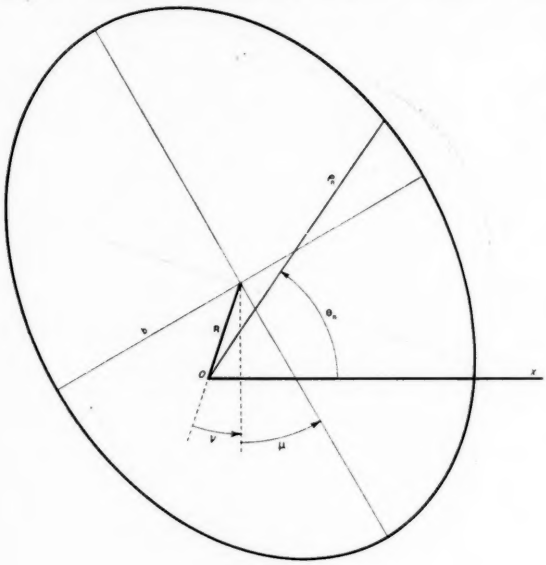

FIGURE 4
TYPICAL FORM OF DISTRIBUTION ELLIPSE

$$[1-e^2\sin^2(\theta_n-\mu)]\,\rho_n^2-R\{(2-e^2)\sin(\theta_n+\nu)-e^2\sin[\theta_n-(2\mu+\nu)]\}\,\rho_n+R^2[1-e^2\cos^2(\mu+\nu)]-b^2=0 \qquad (5)$$

where e is the eccentricity of the ellipse, and, as shown in the figure, b is the semi-minor axis, R the displacement of the center of the ellipse from the pole of the coördinate system, ν the angle between the displacement line R and a normal to the initial line of the coördinate system, and μ the angle between the same normal and the major axis of the ellipse.

Values found (by graphical and numerical procedures) for the constants of the solar system distribution ellipse are given in Table II. Values of ρ_n computed from equation (5), using the constants of Table II, appear in Table III.

TABLE II

CONSTANTS OF DISTRIBUTION ELLIPSE FOR THE SOLAR SYSTEM

$e^2 = 0.2352$	$\mu = \theta_1/3$
$b = 0.1900$ A.U.	$\nu = \theta_1/6$
$R/b = 0.1588$	$\theta_1 = 4\pi/13$

Values of D_n computed from equation (4)′, using solar system values

of ρ_n from Table III are compared with the known mean distances of the various planets in Table IV.

TABLE III

SOLAR SYSTEM VALUES OF ρ_n COMPUTED FROM EQUATION (5), USING THE DISTRIBUTION ELLIPSE CONSTANTS OF TABLE II

n	ρ_n	n	ρ_n
1	.2238937	6	.1950722
2	.2424635	7	.2066141
3	.1936949	8	.2416496
4	.1710605	9	.2205749
5	.1862469	10	.1762333

TABLE IV

COMPARISON OF OBSERVED VALUES OF D_n WITH THOSE COMPUTED FROM $D_n = \rho_n (1.728)^n$

SOLAR SYSTEM

n	Name of Planet	Observed** D_n	Solid Angle† Subtended at System Center	Computed D_n	Ratio	Percent Difference
1	Mercury	.387099	0.579×10^{-8}	.386888	.99946	— 0.054
2	Venus	.723331	1.032×10^{-8}	.723992	1.00091	+ 0.091
3	Earth	1.000000	0.570×10^{-8}	.999423	0.99942	— 0.058
4	Mars	1.523688	0.0693×10^{-8}	1.525193	1.00099	+ 0.099
5	Ceres*	2.767303	0.00027×10^{-8}	2.869509	1.03693	+ 3.693*
6	Jupiter	5.202803	2.53×10^{-8}	5.193472	0.99821	— 0.179
7	Saturn	9.538843	0.510×10^{-8}	9.505306	0.99648	— 0.352
8	Uranus	19.190978	0.0248×10^{-8}	19.210380	1.00101	+ 0.101
9	Neptune	30.070672	0.0097×10^{-8}	30.300493	1.00764	+ 0.764
10	Pluto*	39.45743	0.00082×10^{-8}	41.833607	1.06022	+ 6.022*

*These bodies subtend unusually small solid angles at the system center. "Percent differences" are correspondingly large.

**Values taken from the *American Ephemeris and Nautical Almanac.*

†In steradian measure.

Equations (4)′ and (5) have permitted us to compute the mean distances of the planets from the sun as a function of planet ordinal number. Good agreement with known distances has been obtained. *These same two equations also hold for the mean distances of satellites from their primaries in the satellite systems of Jupiter, Saturn, and Uranus.* Each system has its own characteristic distribution ellipse so that the values of constants in equation (5) change from system to system.

Values of $D_n/(1.728)^n$ for each of the three satellite systems are given in Table V and are plotted against $(4\pi/13)n$ in Figures 5, 6, and 7. The ellipses of these figures were found by trial with an ellipsograph to be those best fitting the plotted points.[3] The values of constants for use in equation (5) for each satellite system were determined by graphical and numerical methods from the fitted ellipses. These values appear in the summary of constants of Table VI.

In assigning ordinal numbers, it was necessary to assume the existence

[3] Since only four plotted points exist for Uranus, a family of ellipses was possible in this case. The particular ellipse shown in Figure 6 was selected on the assumption that certain properties (discussed later) common to other distribution ellipses were also common to that of Uranus.

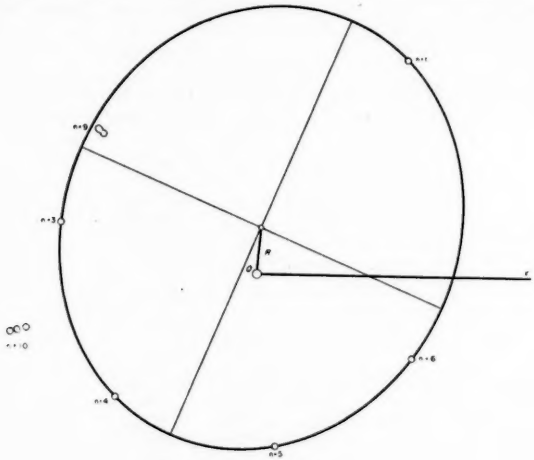

FIGURE 5
VALUES OF $D_n/(1.728)^n$ FOR SATELLITES OF JUPITER
PLOTTED AGAINST $(4\pi/13)n$.

of a few vacancies among known satellites. These were for ordinal numbers 2, 7, 8 in Jupiter's system, number 9 in Saturn's system and number 1 in Uranus' system. Also, in the case of two small satellites of Saturn, it was found necessary to use the ordinal number of an adjacent satellite of superior mass for the exponent of 1.728. The or-

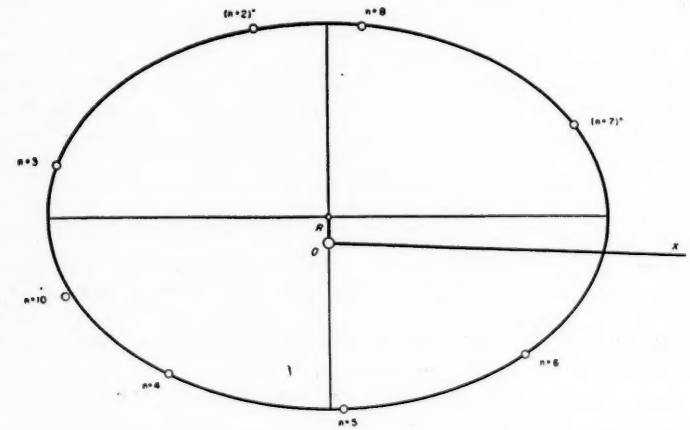

FIGURE 6
VALUES OF $D_n/(1.728)^n$ FOR SATELLITES OF SATURN
PLOTTED AGAINST $(4\pi/13)n$.

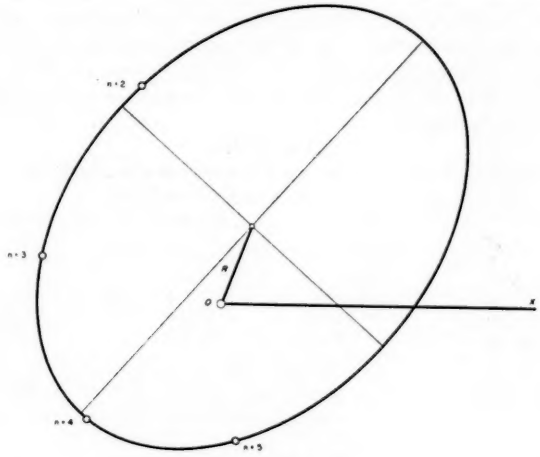

FIGURE 7

VALUES OF $D_n/(1.728)^n$ FOR SATELLITES OF URANUS PLOTTED AGAINST $(4\pi/13)n$.

Note: In the footnote on page 19, for Figure 6 *read* Figure 7; also in Table VI following, for T/2 *read* $\pi/2$.—ED.

dinal number of the large third satellite, Tethys, was used for the exponent in computing D_2 of Enceladus and the ordinal number of the large sixth satellite, Titan, for the exponent in computing D_7 of Hyperion. In all cases, $(4\pi/13)n$ was used for θ_n. The justification for assuming satellite vacancies and for the seemingly arbitrary way of computing D_2 and D_7 of Saturn lies in the results achieved. It should be noted that a unit increase in ordinal number produces a 72.8 per cent

TABLE V

VALUES OF $D_n/(1.728)^n$ FOR THE SATELLITE SYSTEMS OF JUPITER, SATURN, AND URANUS

n	Jupiter	Saturn	Uranus
1	65,162	66,725	.....
2	.....	(28,645)*	39,886
3	50,739	35,467	32,153
4	46,724	26,290	30,529
5	43,110	21,244	23,626
6	43,898	28,501	
7	.....	(34,545)†	
8	.....	27,800	
9	(51,787)	.....	
	(53,083)		
	(53,505)		
10	(59,147)	33,845	
	(61,506)		
	(62,865)		

*$D_2/(1,728)^2$, see text.
†$D_7/(1.728)^6$, see text.

change in $(1.728)^n$. Yet by making the simple changes in ordinal numbering described above, the differences between computed and observed distances immediately became considerably less than one per cent. These results tend to convince one of the correctness of the quantizing-like procedures adopted.

TABLE VI

CONSTANTS OF DISTRIBUTION ELLIPSES FOR THE SATELLITE SYSTEMS OF JUPITER, SATURN, AND URANUS

	Jupiter	Saturn	Uranus
e^2	0.2352	0.5170	0.5170
b	49,210	24,500	30,500
R/b	0.2353	0.1355	0.472
μ	$-5/12\,\theta_1$	$T/2 + 1/24\,\theta_1$	$-3/4\,\theta_1$
ν	$1/12\,\theta_1$	$-1/24\,\theta_1$	$3/8\,\theta_1$
θ_1	$4\pi/13$	$4\pi/13$	$4\pi/13$

TABLE VII

VALUES OF ρ_n COMPUTED FROM EQUATION (5) FOR THE SATELLITE SYSTEMS OF JUPITER, SATURN, AND URANUS

	(Jupiter)	(Saturn)	(Uranus)
n	ρ_n	ρ_n	ρ_n
1	65,227	30,374	.....
2	62,091	28,450	39,976
3	50,610	35,377	32,054
4	46,605	26,341	30,601
5	43,110	21,220	23,647
6	44,018	28,430	
7	56,032	34,485	
8	67,217	27,983	
9	55,392	31,722	
10	48,048	32,910	

TABLE VIII

COMPARISON OF OBSERVED AND COMPUTED VALUES OF D_n FOR THE SATELLITE SYSTEMS OF JUPITER, SATURN, AND URANUS

1. SATELLITE SYSTEM OF JUPITER

n	Name of Satellite	Observed* D_n	Solid Angle† Subtended at System Center	Computed D_n	Ratio	Percent Difference
1	Nameless	112,600	60 $\times 10^{-8}$	112,712	1.00099	+ 0.099
2	....	.....	.....	.....	.....	.....
3	Io	261,800	6170 $\times 10^{-8}$	261,137	0.99747	— 0.253
4	Europa	416,600	1740 $\times 10^{-8}$	415,537	0.99745	— 0.255
5	Ganymede	664,200	1820 $\times 10^{-8}$	664,196	0.99999	— 0.001
6	Callisto	1,168,700	600 $\times 10^{-8}$	1,171,913	1.00275	+ 0.275
7	....	.....	.....	.....	.....	.....
8	....	.....	.....	.....	.....	.....
9	Nameless‡	7,114,000	0.0013 $\times 10^{-8}$	7,609,243	Average	Average‡
	Nameless	7,292,000	0.00092 $\times 10^{-8}$	7,609,243	1.0495	+ 4.95
	Nameless	7,350,000	0.00015 $\times 10^{-8}$	7,609,243		
10	Nameless‡	14,040,000	0.00004 $\times 10^{-8}$	11,405,556	Average	Average‡
	Nameless	14,600,000	0.00023 $\times 10^{-8}$	11,405,556	0.7867	—21.3
	Nameless	14,880,000	0.00013 $\times 10^{-8}$	11,405,556		

*Distance data from *Sky and Telescope*, Vol. I, No. 6, p. 18. April, 1942.

†In steradian measure.

‡These satellites are all very small. Being also at great distances from the system center, the solid angles subtended by them are unusually small. Per cent differences are correspondingly large.

2. SATELLITE SYSTEM OF SATURN

n	Name of Satellite	Observed* D_n	Solid Angle† Subtended at System Center	Computed D_n	Ratio	Percent Difference
1	Mimas	115,300	950 $\times 10^{-8}$	69,680	‡	‡
2	Enceladus	147,800	900 $\times 10^{-8}$	146,900	0.99391	— 0.609
3	Tethys	183,000	1320 $\times 10^{-8}$	182,538	0.99748	— 0.252
4	Dione	234,400	750 $\times 10^{-8}$	234,860	1.00197	+ 0.197
5	Rhea	327,300	890 $\times 10^{-8}$	326,940	0.99891	— 0.109
6	Titan	758,800	920 $\times 10^{-8}$	756,890	0.99749	— 0.251
7	Hyperion	919,700	8.4 $\times 10^{-3}$	718,110	0.99827	— 0.173
8	Iapetus	2,210,000	20 $\times 10^{-8}$	2,224,500	1.00658	+ 0.658
9	....	.....	.....	.....	.....	.....
10	Phoebe§	8,034,000	0.027 $\times 10^{-3}$	7,812,060	0.9724	— 2.76§

*Distance data from "Astronomy" by Russell, Dugan, and Stewart, Vol. I, p. iv.

†In steradian measure.

‡Values not computed. Mimas is the only orbital body in all four systems subtending a relatively large central solid angle whose distance-difference exceeds 0.7 of one per cent. See paragraph 8 below for further discussion.

§This satellite subtends an unusually small solid angle at the system center. "Per cent difference" is correspondingly large.

3. SATELLITE SYSTEM OF URANUS

n	Name of Satellite	Observed* D_n	Solid Angle† Subtended at System Center	Computed D_n	Ratio	Percent Difference
1	....	.....	.....	.....	.....	.....
2	Ariel	119,100	1.53 $\times 10^{-5}$	119,367	1.00224	+ 0.224
3	Umbriel	165,900	0.50 $\times 10^{-5}$	165,394	0.996950	— 0.305
4	Titania	272,200	1.06 $\times 10^{-5}$	272,844	1.00237	+ 0.237
5	Oberon	364,000	0.43 $\times 10^{-5}$	364,334	1.00092	+ 0.092

*Distance data from "Astronomy" by Russell, Dugan, and Stewart, Vol. I, p. iv.

†In steradian measure.

Values of ρ_n for each of the three satellites systems, computed from equation (5) when using the constants of Table VI, appear in Table VII.

Values of D_n for each satellite system *computed* from equation (4)′, using values of ρ_n from Table VII, are compared with corresponding *known* values of D_n in Table VIII. The agreement between known and computed mean distances found here is of the same order as was found in the case of the solar system in Table IV. With few exceptions, differences range from —0.60 to +0.65 of one per cent. These exceptions (in every case and among all systems, except for the first satellite of Saturn) are for orbital bodies that subtend unusually small solid angles at the centers of their corresponding systems. This point is discussed in greater detail in paragraphs 7 and 8 below.

Summarizing, the graphs of Figures 3, 5, 6, and 7, and the numerical comparisons of known and computed values of D_n *appearing in Tables IV and VIII demonstrate that the mean distances of planets from the sun and of satellites from their primaries in the satellite systems of Jupiter, Saturn, and Uranus are in close agreement with particular values*

of the function, D $(\kappa n) \cdot \tau^n$, *of equation* (4). *Suitable universal values for* κ *and* τ *have been given as* $4\pi/13$ *and* 1.728, *respectively.*

In conclusion, the following numbered paragraphs relate to certain generalizations. Some of these may prove to be particularly significant, others may be coincidental; all appear to warrant mention.

1. Adding any constant k to each of the ordinal numbers of a system does not alter the *form* of the system's distribution ellipse. Such a change in ordinal numbering does, however, alter the size of the distribution ellipse by the factor $(1.728)^{-k}$ and rotates it through an angle $(4\pi/13)k$ with respect to the initial line of the coördinate system. Implicitly, this property was utilized when the satellites of Uranus were numbered 2-3-4-5 in place of 1-2-3-4, thereby making possible certain generalizations stated in paragraphs 2, 4, 5, and 6 below.

2. Among the three satellite systems the equatorial diameters of the primary bodies are in approximate agreement with the equation

$$d = 2/5\,[\sqrt{ab/(R/b)}] \qquad (7)$$

where a and b are the semi-major and semi-minor axes of the corresponding distribution ellipse. This relation was formulated after observing that the distribution ellipses of satellite systems have sizes comparable with the equatorial sections of the corresponding central bodies and that the displacement ratios R/b appear to vary directly with deviations from equality in these dimensions. Figure 8 shows graphically the relative sizes of the various distribution ellipses with respect to the sizes

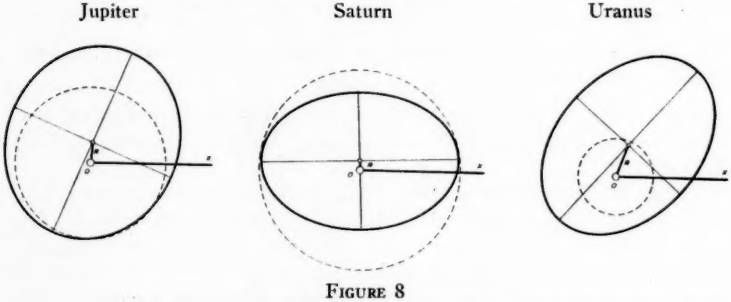

FIGURE 8

DISTRIBUTION ELLIPSES OF THE VARIOUS SATELLITE SYSTEMS COMPARED WITH EQUATORIAL SECTIONS (DOTTED CIRCLES) OF CORRESPONDING CENTRAL BODIES.

TABLE IX

Central Body	$d = 2/5\,[\sqrt{ab/(R/b)}]$	Equatorial Diameter of Central Body
Jupiter	89,450	88,700
Saturn	86,760	75,060
Uranus	31,000	30,880

of corresponding central bodies, the latter being shown by dotted circles. Numerical comparisons of central body diameters with values computed from equation (7) appear in Table IX.

3. The eccentricity of the solar distribution ellipse equals that of Jupiter's distribution ellipse. Similarly, the eccentricities of the distribution ellipses of Saturn and Uranus are equal.

4. In all four systems, the distribution ellipses are displaced *above* the pole of the coördinate system. The angles $90° - \nu$ (between initial line of the coördinate system and the various displacement lines R) range from approximately 69 degrees for Uranus to 92 degrees for Saturn.

5. In each of the four orbital systems considered, the absolute value of the angle between the displacement line R and the major axis of the distribution ellipse is in approximate agreement with the empirical equation

$$|\mu + \nu| = \sin^{-1} 0.178\ (b/R)\ e^2\ (2 - e^2) \qquad (8)$$

Agreement in the case of each system appears in Table X.

TABLE X

COMPARISON OF CHARACTERISTIC VALUES OF $|\mu + \nu|$ WITH THOSE GIVEN BY EMPIRICAL EQUATION (8)

System	(Characteristic) $\lvert\mu + \nu\rvert$	(Equation 8) $\lvert\mu + \nu\rvert$
Solar	27° 41′ 32″	27° 43′ 39″
Jupiter	18° 27′ 42″	18° 18′ 01″
Saturn	90° 00′ 00″	90° 24′ 44″
Uranus	20° 46′ 09″	16° 48′ 25″

6. For each of the three satellite system distribution ellipses, the direction of the displacement line R is such as to lie within 4 degrees of a diameter conjugate to a diameter drawn parallel to the initial line of the coördinate system. This is shown graphically in Figure 9.

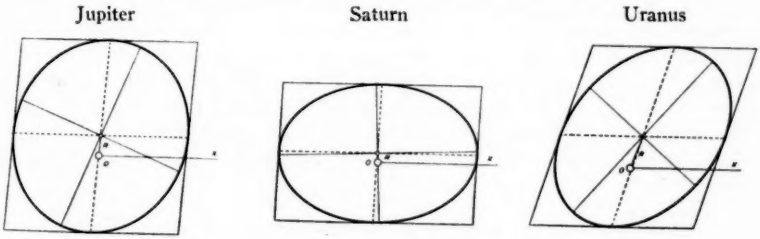

FIGURE 9
CONJUGATE DIAMETERS

7. Relatively large solid angles are subtended at system centers by orbital bodies in 8 out of 10 occupied orbit positions in the solar system, in 5 out of 7 in Jupiter's system, in 8 out of 9 in Saturn's system, and in

4 out of 4 in Uranus' system. If from among these we delete the first satellite of Saturn (whose case is discussed in paragraph 8) and compute the probable error[4] of computed distances of the remaining 24 bodies, we find the probable error to be 0.205 of one per cent, while the greatest single error[4] in computed distance among these bodies is 0.764 of one per cent.

8. Mimas, the first satellite of Saturn, is the only body in all four systems subtending a relatively large solid angle at the center of its system whose computed — observed distance difference exceeds 0.764 of one per cent. The calculated distance for this satellite ($D_1 = 69{,}680$

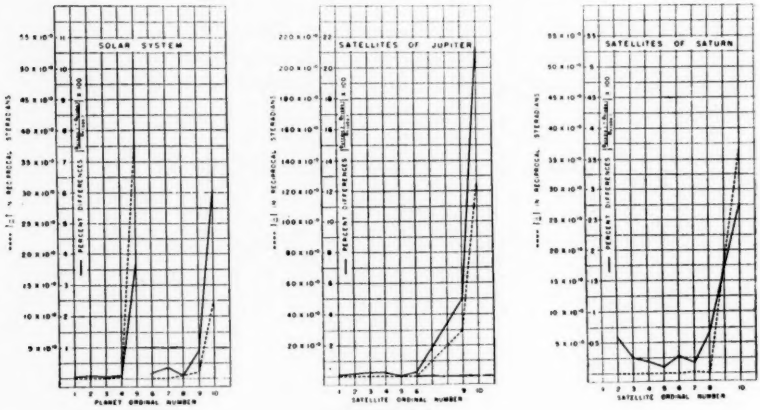

FIGURE 10

GRAPHS SHOWING A DEPENDENCE OF PER CENT DIFFERENCES

$$\left| \left[D_{n\ (calc.)} - D_{n\ (obs.)} \right] / D_{n\ (obs.)} \right| \times 100 \text{ ON SOLID ANGLES } \omega$$

miles) lies approximately 3000 miles inside the outer edge of the 16,000 mile-wide bright B-ring of Saturn. Thus the ordinal number $n = 1$ appears to be associated with the rings of Saturn as well as with satellite Mimas. It may be significant that this is the only instance among the various systems where the computed value of D_1 is less than the diameter of the central body of the system. Saturn's system is also the only system for which the distribution ellipse lies wholly inside the central body.

[4] The word "error" here applies to the difference between distances computed by equations (4)′ and (5), and the known (observed) distance.

Jupiter and Saturn at Solar Opposition

By R. B. WEITZEL

When Jupiter and Saturn are at opposition to the sun within one and three-quarters days of each other there are three conjunctions of the planets within a period of seven and a half months. It may be remarked that triple conjunctions of Jupiter and Saturn are infrequent, averaging seven in ten centuries, or one in a hundred and forty years.

If, within the set limits, the solar opposition of Jupiter follows that of Saturn, then one of the planetary conjunctions in geocentric longitude will be before and two after the oppositions. For example, a solar opposition of Jupiter occurred on September 15, about a day after that of Saturn on September 14, 7 B.C. There were three geocentric conjunctions of the planets on the following dates at the given longitudes:

— 6	V 28	λ 350°.82
	X 5	347.09
	XII 1	345.42

If the solar opposition of Jupiter precedes that of Saturn, then two of the planetary conjunctions in geocentric longitude will be before and one after the oppositions. For example, a solar opposition of Jupiter will occur on March 26, about a day before that of Saturn on March 27, 1981, A.D. There will be three geocentric conjunctions of the planets on the following dates at the given longitudes:

1980	XII 29	λ 189°.28
1981	III 9	187.65
	VII 24	184.80

A list of Jupiter and Saturn solar oppositions within one and three-quarter days of each other is presented. The columns give, in order, year, month, day, hour, Julian day number, longitude of sun, and difference in time between solar oppositions of Jupiter and Saturn.

Jup.	Opp.	Hr.	G.C.T.	⊙	Diff.	Sat.	Opp.	Hr.	G.C.T.	⊙
—3937	III	6, 10	283133.42	314°.91	+0^d 14^h	—3937	III	7, 0	283134.00	315°.48
—3779	VII	17, 5	340976.21	84.70	+0 12	—3779	VII	18, 17	340977.71	86.16
—3660	VIII	1, 16	384456.67	99.93	+1 10	—3660	VIII	3, 2	384458.08	100.33
—3620	XII	27, 14	399214.58	250.03	+0 20	—3620	XII	28, 10	399215.42	250.86
—3440	I	30, 13	464627.54	284.24	—1 3	—3440	I	29, 10	464626.42	283.13
—3401	V	23, 4	478985.17	32.82	—1 9	—3401	V	21, 19	478983.79	31.51
—3362	IX	24, 7	493354.29	155.23	+0 23	—3362	IX	25, 6	493355.25	156.22
—3321	II	11, 9	508104.38	296.94	+1 11	—3321	II	12, 20	508105.83	298.85
—3202	II	24, 9	551582.38	310.18	+1 14	—3202	II	25, 23	551583.96	312.19
—3083	III	9, 18	595060.75	324.63	+1 8	—3083	III	11, 2	595062.08	325.93
—2964	III	23, 3	638539.12	338.59	+1 17	—2964	III	24, 20	638540.83	340.26
—2806	VIII	5, 23	696383.96	109.63	—1 1	—2806	VIII	4, 22	696382.92	108.60
—2508	IX	27, 2	805281.08	164.42	—1 1	—2508	IX	26, 1	805280.04	163.37
—2467	II	16, 0	820033.00	307.91	—1 2	—2467	II	14, 22	820031.92	306.89
—2348	II	29, 2	863510.08	320.78	+1 13	—2348	III	1, 15	863511.63	322.33
—2229	III	14, 0	906988.00	334.48	+1 16	—2229	III	15, 16	906989.67	336.07
—2091	XII	1, 14	957655.58	233.71	—1 12	—2091	XI	30, 2	957654.08	232.19
—1833	VIII	24, 12	1051790.50	134.61	+0 4	—1833	VIII	24, 16	1051790.67	134.77

Jup.	Opp.	Hr.	G.C.T.	☉	Diff.	Sat.	Opp.	Hr.	G.C.T.	☉
—1792	I	18, 13	1066547.54	283°.77	—1 5	—1792	I	17, 8	1066546.33	282°.55
—1535	X	15, 18	1160687.75	189.71	—0 21	—1535	X	14, 21	1160686.88	188.82
—1494	III	4, 22	1175437.92	331.23	—0 5	—1494	III	4, 17	1175437.71	331.02
—1375	III	17, 13	1218915.54	344.60	+1 7	—1375	III	18, 20	1218916.83	345.86
—1118	XII	19, 7	1313061.29	258.18	—0 4	—1118	XII	19, 3	1313061.12	258.00
— 979	VIII	27, 16	1363717.67	144.42	—0 21	— 979	VIII	26, 19	1367716.79	143.55
— 860	IX	10, 20	1407196.79	159.58	+1 3	— 860	IX	11, 23	1407197.96	160.69
— 819	II	3, 13	1421952.54	307.38	+0 22	— 819	II	4, 11	1421953.46	308.28
— 562	XI	3 2	1516094.08	214.86	—0 8	— 562	XI	2, 18	1516093.75	214.53
— 521	III	22, 4	1530843.17	354.92	+0 11	— 521	III	22, 15	1530843.63	355.37
— 144	I	5, 19	1668466.77	282.49	+0 21	— 144	I	6, 16	1668467.67	283.38
— 6	IX	15, 4	1719124.17	169.63	—0 23	— 6	IX	14, 5	1719123.21	168.66
333	III	25, 21	1842770.87	5.43	—1 9	333	III	24, 12	1842769.50	4.10
411	XI	21, 7	1871500.29	240.08	+0 18	411	XI	22, 1	1871501.04	240.85
452	IV	7, 10	1886248.42	18.73	+0 20	452	IV	8, 6	1886249.25	19.58
710	I	9, 10	1980394.42	292.81	—1 5	710	I	8, 5	1980393.21	291.56
967	X	3, 17	2074530.71	195.09	—0 5	967	X	3, 12	2074530.50	194.86
1008	II	25, 11	2089285.46	341.76	—0 13	1008	II	24, 22	2089284.92	341.23
1306	IV	11, 23	2198175.96	29.20	—0 12	1306	IV	11, 11	2195175.46	28.72
1384	XII	8, 6	2226906.25	265.20	+1 13	1384	XII	9, 19	2226907.79	266.77
1425	IV	24, 13	2241653.54	42.56	+1 11	1425	IV	26, 0	2241655.00	43.93
1683	II	5, 17	2335799.71	317.17	—0 4	1683	II	5, 13	2335799.46	317.00
1940	XI	3, 4	2429937.17	220.60	+0 17	1940	XI	3, 21	2429937.87	221.30
1981	III	26, 5	2444690.21	5.48	+0 22	1981	III	27, 3	2444691.12	6.40

There are three cases when the *minus* difference between solar oppositions of Jupiter and Saturn exceeded a day and three quarters but was less than two days. A trial date for each case, about four days before the second stationary point of Jupiter, was taken to determine the likelihood of triple conjunction in geocentric longitude.

Solar Opp. of Jup. and Sat.				Trial Dates and Geo. Long.			
—3918	XI	9, 22^h	☉ 199°.25	—3917	I 4	J	14°.33
Saturn	XI	8, 2	197.37			S	13.93
Diff.		—1^d 20^h					
35	II	8, 13	318.00	35	IV 5	J	133.00
Saturn	II	6, 14	316.04			S	132.70
Diff.		—1^d 23^h					
1265	XI	24, 22	250.46	1266	I 19	J	65.50
Saturn	XI	23, 3	248.64			S	65.25
Diff.		—1^d 19^h					

Since in each instance the geocentric longitude of Jupiter was *greater* than that of Saturn, no conjunction occurred on retrograde or redirect motion, only a single conjunction on direct motion.

There are three cases when the *plus* difference between solar oppositions of Jupiter and Saturn exceeded a day and three quarters but was less than two days. A trial date for each case, about four days after the first stationary point of Jupiter, was taken to determine the likelihood of triple conjunction in geocentric longitude.

Solar Opp. of Jup. and Sat.				Trial Dates and Geo. Long.			
—2389	X	11, 20^h	☉ 179°.35	—2389	VIII 16	J	4°.48
Saturn	X	13, 16	181.25			S	4.83
Diff.		+1^d 20^h					

— 402	IV 3, 23	8.45	— 402	II 8	J	193.23
Saturn	IV 5, 18	10.19			S	193.18
Diff.	$+1^d19^h$					
113	IX 29, 12	185.02	113	VIII 4	J	9.94
Saturn	X 1, 11	186.98			S	10.24
Diff.	$+1^d23^h$					

Since in the first and third instances the geocentric longitude of Jupiter was *less* than that of Saturn, no conjunction occurred on direct or retrograde motion, only a single conjunction on redirect motion. In the second instance, however, the geocentric longitude of Jupiter exceeded that of Saturn, and a triple conjunction occurred as follows:

— 402	II 2	λ 193°27
	II 13	193.09
	VIII 9	188.05

There is no satisfactory recurrent cycle connecting series of tabulated dates. The nearest approach thereto is a period of 973 years, thus formed:

Jupiter synodic revolutions	398.8840 × 891 = 355405.64 days
Saturn synodic revolutions	378.0918 × 940 = 355406.29 days
Julian years	365.2500 × 973 = 355388.25 days
Tropical years	365.2422 × 973 = 355380.66 days

Conjunctions of Jupiter and Saturn in geocentric longitude do not necessarily coincide with conjunctions in right ascension as may be exemplified by a parallel arrangement.

Conjunction in Geo. Long.			Conjunction in Rt. Asc.		
1940	VIII 8, 1^h	44°.35	1940	VIII 15, 13^h	42°.95
	X 20, 5	42.36		X 11, 23	41.43
1941	II 15, 6	39.12	1941	II 20, 19	37.83

In 1503/04, a triple conjunction of Mars and Jupiter occurred in proximity with a triple conjunction of Mars and Saturn. It is highly probable that, during the past six thousand years, no triple conjunction of Mars and Jupiter, or of Mars and Saturn, occurred in proximity with a triple conjunction of Jupiter and Saturn.

Washington, D. C.

Planetary Phenomena for 1945

Note: Greenwich Civil Time is used unless otherwise stated. To convert to Eastern War Time, subtract 4 hours, to Central War Time, 5 hours, etc. The data and charts are taken from the *American Ephemeris and Nautical Almanac* for 1945.

Eclipses

There are four eclipses listed for this year, two of the sun and two of the moon. Only one of them will occur under favorable conditions for observations.

I. An Annular Eclipse of the Sun on January 14. The path of this eclipse is limited almost entirely, as is seen in Figure 1, to the southern part of the Indian Ocean and the South Pacific Ocean. It barely touches the southeastern coast of Africa and skirts the northern shore of Tasmania. It is, therefore,

quite unlikely that any systematic observations of this eclipse will be made. Moreover, it is quite likely that the eclipse will take place before any copy of this issue reaches these far-off places. Nevertheless, for the sake of completeness, we are giving here a chart of the path, Figure 1, and the circumstances of the eclipse as given in the *American Ephemeris*.

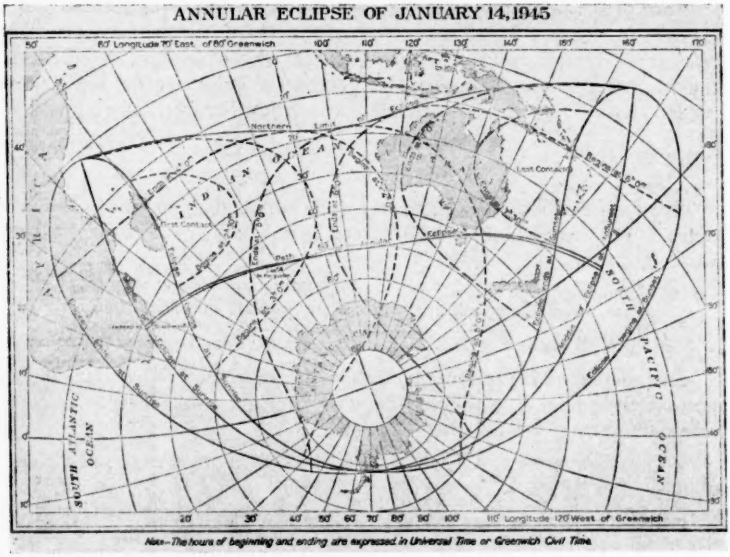
ANNULAR ECLIPSE OF JANUARY 14, 1945
80° Longitude 70° East of 80° Greenwich
110° Longitude 120° West of Greenwich
Note—The hours of beginning and ending are expressed in Universal Time or Greenwich Civil Time.

FIGURE 1

Circumstances of the Annular Eclipse of the Sun of July 14, 1945:

	d	h	m	Longitude ° ′	Latitude ° ′
Eclipse begins	Jan. 14	2	22.0	— 48 0	—21 13
Central eclipse begins	14	3	27.2	— 26 39	—31 21
Central eclipse at local apparent noon	14	4	57.3	—107 55	—51 18
Central eclipse ends	14	6	35.4	+176 45	—23 37
Eclipse ends	14	7	40.5	—162 28	—13 22

II. A Partial Eclipse of the Moon on June 25. This phenomenon, invisible at Washington, will be visible in the Pacific Ocean, the Antarctic regions, Australia, the Indian Ocean, Asia, and parts of Africa. It will probably pass with very little notice on the part of astronomers. However, inhabitants of the regions from which the eclipse will be visible, will have their attention attracted to it, if the sky is clear, whether they have advance notice of it or not. The circumstances of this eclipse are as follows:

	d	h	m
Moon enters penumbra	June 25	12	25.6
Moon enters umbra		13	37.3
Middle of the eclipse		15	13.9
Moon leaves umbra		16	50.7
Moon leaves penumbra		18	2.2

The magnitude of the eclipse will be .865, which means that at the middle of the eclipse more than .8 of the moon's diameter will be in the shadow.

III. A Total Eclipse of the Sun on July 9. This eclipse will arouse some interest although, under present conditions, it will probably not be observed by any special eclipse expeditions. As shown in Figure 2 it will be visible as a partial eclipse over all of North America, Greenland, all of Europe, Northern Africa, Northern and Western Asia. The path of totality will begin in the northwestern part of the United States, cross Canada, Greenland, Norway, Sweden, Russia, and end in southwestern Siberia.

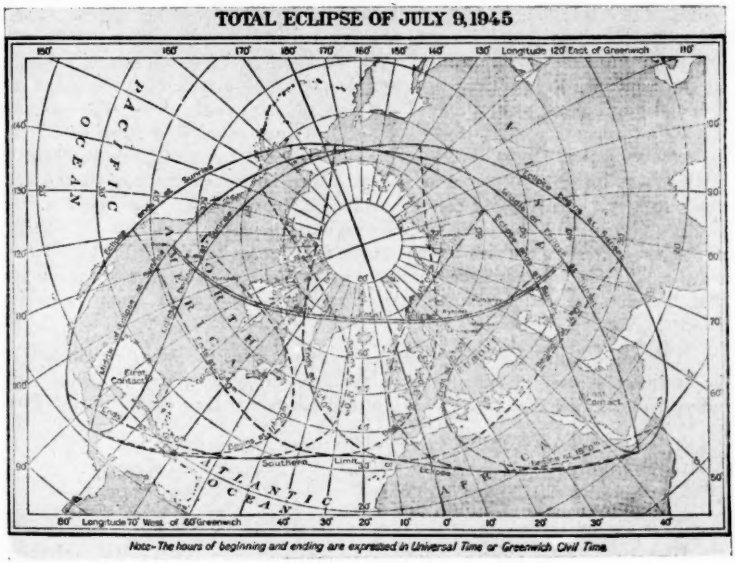
TOTAL ECLIPSE OF JULY 9,1945
Longitude 120° East of Greenwich
PACIFIC OCEAN
ATLANTIC OCEAN
Southern Limit
Longitude 70° West of Greenwich
Note- The hours of beginning and ending are expressed in Universal Time or Greenwich Civil Time.

FIGURE 2

Circumstances of the Total Eclipse of the Sun of July 9, 1945:

	d h m	Longitude ° ′	Latitude ° ′
Eclipse begins	July 9 10 59.6	+ 86 6	+27 38
Central eclipse begins	9 12 13.8	+115 57	+44 23
Central eclipse at local apparent noon	9 13 25.1	+ 20 2	+70 3
Central eclipse ends	9 14 40.9	— 72 33	+41 43
Eclipse ends	9 15 55.2	— 43 25	+24 48

IV. A Total Eclipse of the Moon on December 18-19. This eclipse will be visible generally throughout North and South America, Europe, Asia, except the eastern part, and Africa. It will occur when the moon is near its most northerly point, and hence will afford favorable conditions for observations north of the equator. The moon will pass through the shadow cone at a point at which the diameter of the cone is one and one-third times the diameter of the moon. The circumstances of this eclipse are as follows:

	d	h	m
Moon enters penumbra	Dec. 18	23	38.4
Moon enters umbra	19	0	37.5
Total eclipse begins	19	1	40.5
Middle of the eclipse	19	2	20.3
Total eclipse ends	19	3	0.2
Moon leaves umbra	19	4	3.1
Moon leaves penumbra	19	5	2.3

The Planets

As has been customary for many years, we shall continue to give details concerning planetary configurations from month to month, one month in advance. Here we shall give a general survey of the movements of the planets throughout the year. Heretofore we have used charts of various forms to indicate the times when the several planets would be visible. No such chart is available at this time. In place of such a chart we are giving a table of positions of the sun and the brighter planets on the first day of each month. This table contains all the information a chart would contain. In using the table, it must, of course, be remembered that right ascension increases toward the east. Consequently, if the right ascension of a planet at a certain time is larger than that of the sun, the planet is to the east of the sun and will, therefore, set after the sun. In other words, it will be visible in the west after sunset. If the reverse is true, the planet is west of the sun and the planet is to be looked for in the east before sunrise. As for the angular distance from the sun, one will have a clue in the fact that six hours along the equator is equal to the distance from the zenith to the horizon.

This table is not sufficiently detailed to show when the inferior planets will be at their greatest elongations from the sun. Since Mercury is visible only when it is near these positions, they are listed here for the year.

Greatest Elongation of Mercury from the Sun

Eastern Elongation (Evening Star)	Distance from Sun			Western Elongation (Morning Star)	Distance from Sun		
Date	°	′	Decl. Mag.	Date	°	′	Decl. Mag.
Mar. 26	18	46	+11°.4 +0.2	Jan. 13	23	40	−21°.9 0.0
July 24	27	1	+11.3 +0.7	May 11	26	13	+ 6.3 +0.7
Nov. 18	22	25	−25.4 −0.1	Sept. 6	18	1	+13.2 −0.2
				Dec. 27	22	12	−20.4 −0.1

Venus will begin the year as a brilliant evening star, and will reach a point of greatest eastern elongation early in February. It will then move back toward the sun and pass between the earth and sun about the middle of April. Then it will swing to the west of the sun and reach its greatest elongation west toward the end of June. During midsummer, therefore, it will be a bright morning star. It will probably not attract much attention at this season because it will rise very early in the morning. Venus will remain west of the sun during the remainder of the year. It will be gradually overtaking the sun in its eastern motion and at the close of the year will be only about half an hour west of it.

Because Saturn at this time is favorably situated in that its ring system is inclined so that the southern surface of the rings is visible from the earth, and because this will elicit especial interest in this planet, the diagram of the ring

RIGHT ASCENSIONS AND DECLINATIONS OF THE SUN AND THE BRIGHTER PLANETS IN 1945

		—Sun—	—Mercury—	—Venus—	—Mars—	—Jupiter—	—Saturn—	—Uranus—
Jan. 1	α	18h 44m5	17h 29m5	21h 49m4	17h 44m3	11h 52m1	6h 30m6	4h 33m3
	δ	−23° 3′1	−20° 9′4	−14° 57′9	−23° 56′0	+ 2° 14′8	+22° 29′9	+21° 55′1
Feb. 1	α	20h 56m9	19h 41m8	23h 54m1	19h 25m9	11h 50m8	6h 20m9	4h 30m1
	δ	−17° 15′7	−22° 26′2	− 0° 0′5	−22° 48′8	+ 2° 32′7	+22° 40′2	+21° 48′5
Mar. 1	α	22h 46m3	22h 49m5	1h 21m7	20h 56m0	11h 41m0	6h 16m7	4h 30m0
	δ	− 7° 48′2	− 9° 25′1	+12° 54′6	−18° 25′2	+ 3° 42′1	+22° 46′6	+21° 48′6
Apr. 1	α	0h 40m1	1h 37m7	1h 51m1	22h 30m4	11h 26m6	6h 19m4	4h 33 m2
	δ	+ 4° 18′9	+13° 32′9	+19° 26′8	−10° 42′1	+ 5° 15′4	+22° 50′4	+21° 55′8
May 1	α	2h 31m3	1h 7m6	1h 0m7	23h 56m8	11h 17m4	6h 28m5	4h 38m9
	δ	+14° 53′8	+ 4° 50′0	+10° 11′0	− 1° 44′6	+ 6° 9′1	+22° 49′4	+22° 7′6
June 1	α	4h 34m0	3h 26m0	1h 43m4	1h 23m8	11h 17m9	6h 42m7	4h 46m4
	δ	+21° 58′4	+17° 5′4	+ 8° 42′9	+ 7° 31′1	+ 5° 59′3	+22° 40′9	+22° 21′7
July 1	α	6h 38m2	7h 50m4	3h 26m6	2h 48m3	11h 27m6	6h 59m0	4h 53m9
	δ	+23° 9′3	+22° 56′2	+15° 36′1	+15° 10′2	+ 4° 50′5	+22° 24′0	+22° 34′4
Aug. 1	α	8h 43m2	10h 17m5	5h 43m4	4h 16m4	11h 44m9	7h 16m1	5h 0m4
	δ	+18° 10′6	+ 7° 44′8	+21° 14′4	+20° 39′9	+ 2° 54′0	+21° 59′0	+22° 44′5
Sept. 1	α	10h 39m3	9h 36m2	8h 15m5	5h 42m0	12h 6m8	7h 31m3	5h 4m5
	δ	+ 8° 30′2	+12° 45′7	+19° 25′0	+23° 14′1	+ 0° 28′6	+21° 30′8	+22° 50′4
Oct. 1	α	12h 27m4	12h 25m3	10h 39m1	6h 56m3	12h 30m3	7h 42m1	5h 5m3
	δ	− 2° 57′4	− 1° 13′9	+ 9° 41′2	+23° 18′0	− 2° 4′0	+21° 8′1	+22° 51′8
Nov. 1	α	14h 23m3	15h 32m0	13h 1m4	7h 55m8	12h 54m7	7h 47m1	5h 2m8
	δ	−14° 14′8	−21° 2′6	− 4° 47′4	+22° 10′1	− 4° 38′1	+20° 57′9	+22° 48′7
Dec. 1	α	16h 26m8	17h 25m3	15h 25m3	8h 24m2	13h 16m3	7h 44m9	4h 57m9
	δ	−21° 43′1	−23° 50′8	−17° 38′1	+21° 56′3	− 6° 48′1	+21° 5′9	+22° 42′1

system and apparent orbits of the seven inner satellites, taken from the *American Ephemeris*, is given here as Figure 3.

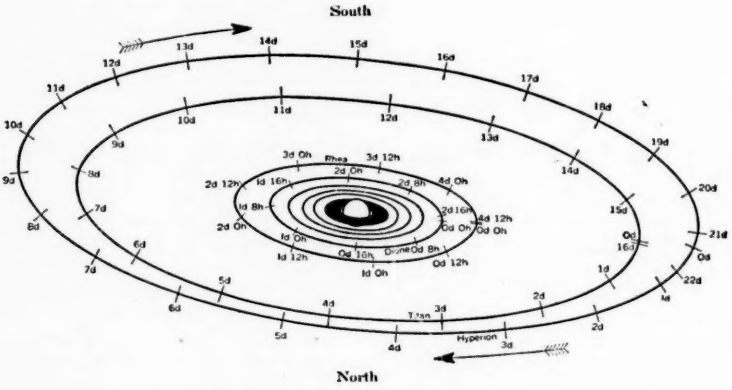

FIGURE 3

NAMES OF THE SATELLITES	APPARENT ORBITS OF THE SEVEN INNER SATELLITES OF SATURN, AT DATE OF OPPOSITION, JANUARY 12, 1946, AS SEEN IN AN INVERTING TELESCOPE.	MEAN SYNODIC PERIODS
I. Mimas		I. 0 22.6
II. Enceladus		II. 1 8.9
III. Tethys		III. 1 21.3
IV. Dione		IV. 2 17.7
V. Rhea		V. 4 12.5
VI. Titan		VI. 15 23.3
VII. Hyperion		VII. 21 7.6
VIII. Iapetus		VIII. 79 22.1
IX. Phoebe		IX. 523 15.6

As already stated, other details relating to the several planets will be given in the successive issues.

The Planets in February, 1945

NOTE: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern War Time subtract 4 hours, Central War Time, 5 hours, etc. The phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac*.

Sun. The sun will continue its northeastward course during the month, moving from Capricornus into Aquarius. Its coördinates will change from $\alpha = 20^h\ 57^m$, $\delta = -17°\ 16'$ on February 1 to $\alpha = 22^h\ 43^m$, $\delta = -8°\ 11'$ on February 28.

Moon. The phases of the moon will occur as follows:

	h m
Last Quarter	Feb. 5 10
New Moon	12 18
First Quarter	19 9
Full Moon	27 0

It will be farthest from the earth on February 3 and nearest the earth on February 14.

Mercury. Mercury, starting this period from a position west of the sun, will move eastward more rapidly than the sun and overtake it on the last day of the month. It will then be on the far side of the sun, at superior conjunction, and invisible. In fact it will be lost in the rays of the sun throughout the month. It will be a few degrees south of the sun.

Venus. Venus will be on the equator and about three degrees east of the sun on February 1. It will therefore continue to be very conspicuous in the evening sky. It reaches its farthest point east of the sun on February 2. It will also be nearly at maximum brightness at that time. It will be in the constellation Pisces.

Mars. Mars will be following the sun eastward, but moving more slowly than the sun. This situation will cause it to rise earlier from morning to morning. However, even at the end of the month it will rise less than two hours before the sun. It will be about twenty degrees south of the sun.

Jupiter. Jupiter being near a point of opposition has a slow retrograde motion during the month. Toward the end of the month it will be above the horizon nearly all night. It will be near the western boundary of the constellation Virgo.

Saturn. Like Jupiter, Saturn will be moving westward slowly. It will be above the eastern horizon at sunset and hence will be observable during most of the night. It will be in Gemini, a short distance southwest of Castor and Pollux.

Uranus. Uranus will maintain its position a little less than two hours west of Saturn. It will be due north of Aldebaran at a distance approximately equal to that between the Pointers of the Great Dipper. On February 28 it will be at quadrature, ninety degrees east of the sun.

Neptune. Neptune will cross the meridian a short distance south of the equator about 2 A.M. It will be a short distance northwest of Spica. Its co-ördinates on February 14 are $\alpha = 12^h\,25^m$, $\delta = 1°\,4'$.

Pluto. The position of Pluto, as given by the Nautical Almanac Office for February 18 is $\alpha = 8^h\,51^m.5$, $\delta = +23°\,56'$.

Occultation Predictions for February, 1945

(Taken from the *American Ephemeris*)

Date 1945	Star	Mag.	IMMERSION Green-wich C.T.	IMMERSION a	IMMERSION b	IMMERSION Angle E from N	EMERSION Green-wich C.T.	EMERSION a	EMERSION b	EMERSION Angle E from N
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
Feb. 3	80 Virg	5.8	11 52.8	—0.6	—3.0	169	12 43.3	—1.6	—0.8	247
6	θ Libr	4.3	10 3.1	—3.4	+3.1	53	10 41.4	+0.2	—3.1	357
19	119 H'Taur	6.2	23 2.7	..	..	145	23 25.4	..	..	177
20	302 B.Taur	6.1	5 42.7	+0.1	—1.5	102	6 34.6	+0.2	—0.6	248
21	ξ Taur	3.0	3 34.4	—2.1	+3.5	21	4 3.1	..	..	335
22	BD+22°1416	6.3	5 55.7	—1.6	+1.3	34	6 25.0	+0.8	—4.0	339
23	149 B.Gemi	6.4	1 6.5	..	..	157	1 44.3	..	..	209
24	49 B.Canc	5.9	0 19.3	..	..	19	0 38.3	..	..	352

OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′

Feb. 6		θ Libr	4.3	9	22.0	—1.1	+1.1	96	10	33.0	—1.0	—0.4	316
19	119	H⁵Taur	6.2	22	12.2	—2.1	0.0	114	23	6.0	—0.7	+3.4	202
20	302	B.Taur	6.1	5	48.8	0.0	—2.7	129	6	32.2	—0.6	+0.4	220
21		ξ Taur	3.0	2	53.8	—2.0	+1.7	45	3	57.9	—1.4	—2.6	303
22	BD+22°1416		6.3	5	28.0	—1.6	—0.3	70	6	33.3	—0.5	—2.2	301
23	149	B.Gemi	6.4	0	30.7	—2.7	—4.0	155	1	2.2	..	..	201

OCCULTATIONS VISIBLE IN LONGITUDE +120° 0′, LATITUDE +36° 0′

Feb. 7	68	B.Ophi	5.9	13	58.5	—1.2	—0.7	137	15	16.6	—2.6	+0.4	264
21		ξ Taur	3.0	1	53.6	—1.2	+2.8	40	3	3.6	—2.6	—1.0	291
22	BD+22°1416		6.3	4	31.9	—2.4	—0.4	98	6	0.7	—2.1	—0.3	262
24		ε Canc	6.3	11	21.4	—0.4	—1.2	91	12	18.2	+0.3	—1.7	304
24	102	B.Canc	6.5	11	23.4	—0.9	—0.2	60	12	3.4	+0.6	—2.7	336
28		ν Virg	4.2	4	38.7	—0.7	+2.0	77	5	37.4	—0.9	—1.5	330

OCCULTATIONS VISIBLE IN LONGITUDE +98° 0′, LATITUDE +30° 0′*

Feb. 6		θ Libr	4.3	9	14.3	—0.3	—0.6	137	10	23.3	—1.6	+0.7	277
8	58	Ophi	4.9	11	34.8	..	..	30	11	51.6	..	..	3
20	BD+18°661		Var.	0	09.6	—2.6	+0.1	95	..	..	..	..	...
20	BD+20°969		6.9	21	51.1	—1.2	+0.6	103	..	..	..	..	...
21		ζ Taur	3.0	2	29.0	—2.5	+0.3	82	3	59.6	—2.1	—0.3	263
21	14	Gemi	6.7	21	20.0	—0.6	+0.3	114	..	..	..	..	...
22	BD+22°1364		7.2	0	42.8	—1.5	+2.1	59	..	..	..	..	...
22	BD+22°1416		6.3	5	26.1	—1.6	—1.7	110	6	42.4	—1.3	—0.7	263
23	BD+22°1687		6.9	0	42.0	..	..	20	..	..	..	..	...
23†	49	B.Canc	5.9	23	23.8	+0.1	+2.3	53	0	17.7	—1.3	—0.5	307
24		ε Canc	6.3	11	29.8	+0.2	—0.7	80	..	..	..	..	...
24	102	B.Canc	6.5	11	35.9	—0.4	+0.9	43	..	..	..	..	...
28		ν Virg	4.2	4	58.9	—2.0	+1.0	90	6	15.0	—1.4	—2.3	330

*Computation by George R. Schaefer and Paul Herget, communicated by Captain V. K. Coman, Superintendent U.S. Naval Observatory.

†Emersion on the following day.

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

The month of October, during the epoch of the Orionids, had many clear nights in this part of the country. Several observers sent in good observations on this stream, and a few sent in something on the Leonids in November. It is also known that some work which was done has not yet arrived here, so the following table is far from complete.

Observer and Station	1944 Date m	d	Began	Ended	Min.	s →	F	Rate	Notes
C. Erman, Hartford, Conn.	10	17	12:45	15:00	195	22	1.0	7	p
" "	10	21	11:40	15:15	175	25	1.0	9	p
" "	10	22	13:35	15:40	125	18	1.0	9	p
R. M. Hukill, Wilmington, Del.	10	22	12:45	13:00	75	36	0.9	29	c
R. Wissert, Buffalo, N. Y.	10	22	15:50	16:50	60	10	1.0	10	p—
A. Madans, Yonkers, N. Y.	10	21	11:00	14:40	220	48	1.0	13	d
S. Barowitz, New York, N. Y.	11	12	10:00	10:30	30	6	1.0	12	p
" "	11	18	11:00	12:45	105	5	0.9	3	p
B. Stowe, Yonkers, N. Y.	10	15	8:30	9:30	60	5	1.0	5	p
" "	10	21	11:45	15:00	195	43	1.0	13	p
" "	11	10	9:00	11:00	120	7	0.4	..	p
" "	11	11	9:00	11:15	135	18	1.0	8	p
" "	11	18	10:25	16:00	140	9	0.4	..	p
K. Weitzenberger, Bronx, N. Y.	10	14	14:00	15:43	90	15	1.0	10	p
" "	10	15	14:30	15:30	60	10	1.0	10	p
" "	10	17	14:30	16:30	120	17	1.0	8	p
" "	10	21	14:30	16:30	120	11	0.9	6	p
R. M. Dole, Cape Elizabeth, Me.	10	18	15:00	16:00	60	3	1.0	3	p
" "	10	21	12:30	13:30	60	18	...	18	p
" "	11	14	15:00	16:00	60	2	1.0	2	p
" "	11	15	14:00	15:00	60	0	0.3	..	.
C. P. Olivier, Flower Obs., Pa.	10	18	13:25	15:30	120	24	0.8	12	p
" "	10	22	13:20	16:00	150	34	0.9	14	p
Miss E. Sandmeyer, Buhl, Idaho	10	16	14:35	15:35	60	9	...	9	c
" "	10	17	15:15	16:15	60	15	...	15	c
" "	10	18	14:15	15:15	60	18	...	18	c
" "	10	19	14:25	15:25	60	28	...	28	c
" "	10	19	15:30	16:30	60	37	...	37	c
Miss D. E. Beetle, Davis, Calif.	10	20	13:05	14:05	60	16	0.7	16	p
" "	10	21	11:20	12:25	65	14	1.0	13	p
Marion Cole, Merced, Calif.	11	15	13:06	14:06	60	27	...	27	p
J. Leerman, Baltimore, Md.	10	21	16:30	17:30	60	17	...	17	c

Note: Standard Time used. In last column, p means meteors plotted, c counted, d paths or meteors described.

The Orionid epoch was notable in 1944 for the large number of bright fireballs reported, some of them sporadic, others Orionids. They were seen both in the course of regular observations and by casual observers who kindly reported them. Among the outstanding ones was that on October 22 at 14:04, E.S.T., which was one of the finest ever seen by me. (Note that all dates and times given in Meteor Notes are in *old* astronomical reckoning and hence 12 hours behind civil reckoning.) It had a very long path from $\alpha = 334°$, $\delta = +36°$ to $\alpha = 85°$, $\delta = +47°$, taking 3+ seconds to cover this distance. It began as a +3 magn. meteor, constantly increased in brilliancy until, at its final flare, it was —8 magn. It left a 1 sec. train all the way, but from about 12° to 20° of the end, the train lasted 10 seconds. Had it been in my zenith instead of low, where there was slight haze, probably it would have remained visible a full minute at least. The fireball's color was orange, but at the end definitely purple. Its projected path missed the Orionid radiant far enough to make it undoubtedly a sporadic fireball. I have been unable to secure a second observation from a distance, so the height of this superb object cannot be calculated. However, a number of other fireballs on this and nearby nights were reported as a result of a request in the papers. When I have time to work on these it is possible I may be able to compute some paths and heights, and surely will be able to derive a number

of fine radiants from the meteors which were plotted by our observers. As for the richness of the Orionids, the 1944 return was about average; there are too few data at hand as yet to remark intelligently upon the number of Leonids which returned in November.

With the coming of 1945, will it not be possible for our A.M.S. members, who were wholly or partially inactive in 1944, to do at least some observing? Despite the added burdens on time and attention due to the war, very many people have plenty of leisure. Could not some of this be spent in meteor observing? Members are also requested to send in their annual dues of $1 without forcing me to send bills. The time wasted in doing the latter could so much better be spent in reducing some of our accumulated data. We now have a full supply of newly printed maps and blanks, so all requisitions can be filled at once. The A.A.V.S.O. observers manage to keep up a very high standard of achievement, despite the war, so why cannot the A.M.S. members follow their good example by making 1945 an outstanding year?

During the past several years Miss Edith F. Reilly has been working off and on as a volunteer or part-time assistant at Flower Observatory. Recently she was appointed to the staff of the U.S. Naval Observatory. During the periods spent here she was largely engaged in reduction of meteor work of various kinds, a good deal of which has appeared already in Meteor Notes or elsewhere in Popular Astronomy. When she left, she had already finished or partly finished a number of solutions for meteor heights which now await checking by me. Other pressing work has prevented my doing most of this. The following case, however, done by her, has been partly checked by me and is ready for publication. In fact, before solutions were started she usually consulted with me as to method of procedure and about any specially difficult or obscure points.

Fireball of 1932 May 13

For this date at 9:32 P.M., C.S.T., two observers in Texas reported a brilliant fireball. Unfortunately the data are incomplete and the solution suffers as a result. The observations (condensed) are: S1, Guy Borden, $\lambda = 98° 29'$ W, $\phi = 29° 24'$ N, began "slightly W of due N" at $h_1 = 48°$, ended "S of E" at $h_2 = 30°$. Diameter 20'. S2, G. F. Townsend, 9:32 P.M., $\lambda = 97° 43'$ W, $\phi = 30° 15'$ N, a_1 not given, $h_1 = 45°$; $a_2 = 350° \pm$, $h_2 = 10°$; very bright, diameter 15'; green, trail of red sparks. For S1, a_1 was taken as 175° and a_2 as 280°. After two approximations, Miss Reilly obtained:

Date	1932 May 13, 9:32 P.M., C.S.T.
Sidereal time at end point	187°.1
Began over	$\lambda = 98° 33'$ W, $\phi = 30° 06'$ N, at 85.4 ± 1.4 km
Ended over	$\lambda = 97° 31'$ W, $\phi = 29° 14'$ N, at 38.3 ± 17.3 km
Length of path	145 km
Projected length of path	138 km
Radiant (uncorrected)	$a = 134°$, $h = 71°.8$; $\alpha = 92°$, $\delta = +46°.7$

Due to the poor data it seems useless to compute a zenith correction and a corrected radiant. Fireball No. 155, in the von Niessl-Hoffmeister Catalogue, seen on 1909 May 14, has a radiant within 10° in right ascension, and 2° in declination. A silghtly smaller slope for the fireball just discussed would give a close agreement in their radiants.

As a final word, may I request any readers who have fireball observations of any past date whatever to please let me have copies? One such might be the

means of making possible an excellent solution for the case. Also will any member of the A.A.V.S.O. who has any observations of telescopic meteors, or who would be willing in future to make them, kindly get in touch with me.

Flower Observatory, Upper Darby, Pa., 1944 Dec. 16.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles 24

On the Cause of the Hissing Sounds Heard during the Flight of Certain Meteorites

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ABSTRACT AND INTRODUCTION

The following account of a recently observed fireball establishes the objective reality of hissing sounds heard *during* the flight of some fireball-producing meteorites. I have suggested an explanation of the phenomenon, which I hope will be found interesting to readers of *C.S.R.M.*

Two perfectly reliable reports have been received from persons (well-known to me for a number of years for their good education and general knowledge) about a fireball observed on 1944 August 6, in the city of Hyderabad, at about 8:30 P.M. I. S. T. ($= 14^h\,00^m$ U. T.).

Observer No. 1, M. M. Ali Beg, headmaster of a large, west-suburban high school, reports that he was seated at his house, out in the open, when he noticed a sudden flash near the zenith. He at once suspected a fireball and very attentively watched for all of its concomitant phenomena, having heard from me, on prior occasions, of their importance. The meteor was as bright as the Moon at quadrature and proceeded in a path curved downwards directly towards the west. At about 45° from the zenith it disappeared. Thruout its track, for a period of 7 or 8 seconds, he saw sparks proceeding continuously from the nucleus of the fireball, to the right and to the left of the track, *accompanied simultaneously* by a hissing sound, reminding him of the sparks and sound observed when a cutter sharpens a knife on his grinding wheel. The train of the meteor persisted for a few seconds in the wake of the nucleus. It was about half a degree or more wide, bluish-white at the middle at first and orange-colored at the sides. It appeared gradually to swell up laterally, and the middle portion became thinner and finally turned hollow. The "head" of the meteor was distinctly red. This first observer does not remember hearing the sound of an explosion following the extinction of the fireball. The weather was perfectly calm, no wind or local noises disturbing the attention of the observer at his house.

The second observer, M. A. Latif Khan, a legal practitioner, corroborates the light and color details described by the first observer, but, happening to be in the midst of noisy city traffic at the time, he did not hear any hissing sound accompanying the meteor.

I am inclined to think that this particular fireball was due to a very friable aerolite that *gradually* broke up and became dispersed in the upper atmosphere. *The hissing sound is an objective reality.* I myself remember having heard it on similar occasions. It is most probably due to the continuous influx of *matter* moving with parabolic velocity, penetrating right into the lower regions of the atmosphere and resulting from the dissipation of the incandescent meteorite in flight thru its violent collisions with air molecules.

Assuming the fireball-producing meteorite to be at a height of 75 miles and to be moving with a velocity of about 26 miles per second (the solar parabolic velocity at the Earth's distance from the Sun), we find that *matter* from it can reach the lower regions of the atmosphere, *near* an observer, within 4 seconds, thus causing the impression of simultaneity of flash and hissing sound during the latter part of the flight of the meteorite.

It is interesting to compare an account of a fireball observed at Hyderabad on 1936 October 13 and described by me in *Science and Culture* (Calcutta), **2**, No. 5, 273-4, 1936, and briefly mentioned also in *P. A.*, **45**, 42, 1937. The following extract from the letter, contained in the first-named source, furnishes strong evidence in support of my argument:

"Mr. M. T. Ali (Hyderabad Finance Department) stated that he was seated in the open air in his compound (near Golconda), close to a mango tree. Soon after the fireball appeared, he and a number of persons nearby heard distinctly the sound of a shower of fine sand beating against the leaves of the tree. A similar sound was heard by the inmates of another house in the neighborhood, as if fine grains of sand fell onto the leaves of an almond tree in their compound. There can be no doubt about the fall of such fine dust from the bursting of a fireball [-producing meteorite]. But attempts to pick up some of this cosmic material completely failed. No wonder, because the particles must have been exceedingly fine."

I have reported this matter and accounts of two earlier fireballs of this year likewise to Professor Charles P. Olivier. It is my conviction that the number of "fireball"-producing meteorites reaching our atmosphere is very much larger than is generally realized and that meteoritic matter dropped from them can be recovered in very appreciable quantities if the intelligent public will take more than a merely passing interest in the nature and origin of meteorites.

1944 August 28

Four More Cavour, South Dakota, Siderites Found

The Cavour, South Dakota (coördinate number = 0980,443), fall of siderites was noted in *C.S.R.M.*, **3**, 119-20; *P. A.*, **51**, 567-8, 1943. Under the heading of "Cavour Meteorites," Mrs. W. J. Lindsey of Cavour, South Dakota, writes further concerning this fall in *The Mineralogist* (Portland, Oregon), **12**, 388, Dec., 1944, as follows:

"In a paper appearing in the October, 1943, issue of *The Mineralogist*, the writer described a number of meteorites [3] found near Cavour, South Dakota. Since then, 4 additional specimens have been found. A photograph of 3 of these specimens [not reproduced here] is attached.

"The largest shown in the photograph weighs 12½ lb. and is in the collection of the U. S. National Museum at Washington. The small meteorite weighs 1 lb. and is in the collection of Mrs. C. S. Ferguson of Colfax, Iowa.

"The third specimen in the photograph weighs 8 lb. and is in the collection

of the writer. This specimen shows the typical flight-mark imprints. None of these specimens is for sale. The writer is willing to supply any additional information readers of *The Mineralogist* may require."

A Simple Test for Nickel in Meteorites

All meteoritic iron, as far as recognized, is alloyed with nickel. Iron meteorites (siderites) are composed of about 70% to 95% iron and 30% to 5% nickel. A certain amount of nickeliferous iron is present, in the form of small grains, in most stone meteorites (aerolites). The following, well-known "Simple Test for Meteorites" is taken from an issue of *Ward's Mineral Bulletin* (published by Ward's Natural Science Establishment, Rochester, New York) and is repeated here, for convenience of reference, because of its usefulness to students and collectors of meteorites:

"Iron meteorites [siderites] are composed of iron and nickel. Stone meteorites [aerolites] also have varying amounts of these elements. A chemical test for nickel, therefore, will rule out immediately a large number of objects commonly mistaken for meteorites. A simple and positive test for nickel is as follows:

"Break off a fragment of the supposed meteorite and, if possible, powder it or at least break it into small pieces. Dissolve about a gram of this material in dilute nitric acid. Now add ammonium hydroxide until the solution is distinctly alkaline. Use litmus paper for testing the alkalinity. A precipitate of ferric hydroxide will then be formed if iron is present.

"Allow this precipitate to settle and then decant a portion of the clear liquid or filter the precipitate by passing the solution thru filter paper. Next, saturate about one ounce of alcohol with dimethylglyoxime and then add a few drops of this solution to the clear liquid prepared as described. A scarlet-red precipitate will indicate the presence of nickel and the probability that the specimen tested is a meteorite. Dimethylglyoxime can be obtained from any chemical supply house. An ounce costs usually about 75c.

"When you find specimens that you believe to be meteorites, make this simple test."

President of the Society: LINCOLN LA PAZ, Department of Mathematics, Ohio State University, Columbus 10

Secretary of the Society: C. H. CLEMINSHAW, Griffith Observatory, P. O. Box 9866, Los Feliz Station, Los Angeles 27, California

Note on an Unusual Meteor

A third magnitude meteor with a sinusoidal path was observed by the author, using a 4X opera glass, on December 4, 1944, at 10:29 P.M., Eastern Standard Time. This time may be in error by 1 minute. The meteor required roughly three-fourths of a second to pass from $\alpha = 104°5$, $\delta = +20°7$, to $\alpha = 111°2$, $\delta = +27°6$ (1900), which corresponds to an angular velocity of 12° per second. The beginning and end points were not noted. This path was apparently sinusoidal, with a double amplitude of about 10′ or 15′, and a period of very roughly one-quarter second. The meteor was golden yellow and about 5′ in diameter, and was followed by a trail ½° long. This value, combined with the angular velocity, indicates that the duration of visibility of the matter forming the trail was 0.04 seconds.

This observation was made one-quarter mile north of Leesburg, Loudoun

County, Virginia. Corresponding observations (which should have been possible in the Baltimore-Washington area) would be of interest, as knowledge of the height would permit calculation of the linear dimensions of the sinusoid.

JOSEPH ASHBROOK.

Leesburg, Virginia.

Comet Notes

By G. VAN BIESBROECK

The lull in cometary activity continues. Nothing further has been learned about COMET 1944 *e* (BERRY), an object visible to the naked eye when discovered last September in New Zealand, but apparently soon lost in the sun's rays.

The only comet under observation is PERIODIC SCHWASSMANN-WACHMANN I, but it has been recorded as always faint at this opposition. In the past enormous changes in brightness have characterized this unusual object and we must expect it to brighten up again for short intervals. It is, however, difficult to get a continuous record of its behavior: the small inclination of the orbit keeps the comet always in the vicinity of the ecliptic and every month the visiblity is limited to moonless nights. One cannot tell what happens in the meantime and from previous experience we must presume that the outbursts of brightness will be of short duration. When last seen here (Dec. 13) the object was hardly as bright as a 16th magnitude star.

Cloudy weather has prevented the search for COMET 1944 *d* (VAN GENT) which might perhaps yet be in reach as it rises before daylight.

Mr. Edw. H. Pilsworth of Battle Creek, Michigan, writes that he has noticed a comet-like object with a tail about 15′ in length by means of 3-inch refractor of his own construction. From the indication obtained from him the location would have been

		α	δ
1944	Oct. 13	$18^h\ 53^m$	$+41°$
	Nov. 23	17 30	+49

A request for a search on Harvard Sky patrol plates has not brought out any confirmation to date so that it is not clear what this observer may have noticed.

Williams Bay, Wisconsin, December 15, 1944.

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editor may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

Pluto's Advance of Perihelion

It is Mercury's large eccentricity, together with its small distance from the sun, that renders Mercury's advance of perihelion such a crucial test of Einstein's general theory of relativity. Mercury's period also enters into Einstein's formula

$$24\,\pi^3\,a^3/[C^2\,T^3\,(1-e^2)]$$

for advance of perihelion,[1] but the periodic element is taken into account indirectly, by means of the period's relation to the mean distance from the sun by Kepler's harmonic law. The elements of the other planets are, of course, also subject to Kepler's law and Einstein's supplementary relationship of a perihelion advance, but while their distances (and periods) are all greater than Mercury's, certain of the eccentricities are larger, while others are smaller than Mercury's.

Thus, many of the asteroids have even larger eccentricities than Mercury's, but close proximity to Jupiter, Mars, and to each other, introduces so many "perturbing" factors, that the Einstein advance of perihelion is observed by them. Mercury, too, is subject to planetary perturbations, and their existence serves to raise doubts as to the "sufficiency" of the perturbative *residuals* as a decisive test of Einstein's predicted advance of perihelion! Such an objection cannot be maintained with repect to the planet Pluto however.

Pluto is located at the outer, rarefied limits of the solar system and is thus free of the perturbative complications of Mercury's apsidal motion. Pluto, moreover, has an even larger eccentricity than Mercury, so that Pluto's advance of perihelion should prove an especially crucial test of whether orbital eccentricities are so truly decisive in determining apsidal motion as Einstein's formula would seem to suggest. Substituting accepted values of Pluto's major semi-axis, period, and eccentricity in Einstein's formula, we get

$$(24 \times 31 \times 5.90 \times 10^{14(2)})/[8.998 \times 10^{20(2)} \times 7.81 \times 10^{0(2)}\ (1 - .249^2)]$$
$$= (2.589 \times 10^{29})/(5.15 \times 10^{10}) = 5.027 \times 10^{-9} \qquad (1)$$

This is in terms of radians per revolution. To get the observational value in seconds of arc per century, as determined from the earth, we have to convert this to seconds of arc and divide by Pluto's sideral period in years, obtaining

$$(5.027 \times 10^{-9} \times 2.06265 \times 10^{5''})/(2.47697 \times 10^{2}) = 4.161 \times 10^{-6''} \text{ yearly;}$$
$$\text{or } 4.161 \times 10^{-4} \text{ per century.} \qquad (2)$$

This is a rather small amount. But one of the principal functions of theoretical prediction is to sharpen observational procedures so as to decide between alternative predictions. Pluto's unique characteristic of a virtually unperturbed and uncomplicated motion of perhelion renders an observational check upon its apsidal motion especially desirable.

DAVID SHECHTMAN.

October 11, 1944, 1271 - 41 Street, Brooklyn, New York.

[1] A. Einstein, "The Meaning of Relativity," p. 106.

General Notes

Sir Arthur Stanley Eddington, the well-known English scientist and philosopher, Plumian professor of astronomy and director of the observatory of the University of Cambridge, died on November 22 at the age of sixty-one years. We hope to publish a brief biography in the near future.

Mr. Paul E. Wylie, B.S., C.E., of 2319 St. George St., Los Angeles 27, California, author of "The Essentials of Modern Navigation," now in its 5th (1944) edition (Harper), has been teaching courses in navigation in the Depart-

ment of Astronomy of the University of California, Los Angeles, during the summer and fall terms of the academic year 1944-45.

Dr. Frederick C. Leonard, of the University of California, Los Angeles, on November 27, 1944, delivered a lecture, under the Alexander F. Morrison Foundation of the Astronomical Society of the Pacific, at the Santa Barbara Museum of Natural History, on "Meteorites: Immigrants from Space." The lecture was illustrated with specimens and slides. A similar lecture will be given before the Tuesday Evening Forum, meeting at the Pasadena Junior College, on February 20, 1945.

The University of Chattanooga is conducting a somewhat enlarged astronomical program during this academic year. The recently erected observatory is equipped with a 20½-inch reflector with suitable accessories. As a feature for the community, the observatory will be available one evening each week during the school year, weather permitting, to students of Chattanooga schools and adult citizens. Mr. Clarence T. Jones, the architect of the building, is serving also as instructor in astronomy and director of the observatory.

The Cleveland Astronomical Society

At the November meeting of the Society a short business session was held at which officers were elected as follows:

President.....Dr. J. J. Nassau
First Vice President.....Mr. James Russell
Second Vice President.....Mr. Robert Ingle
Secretary-Treasurer.....Miss Virginia Burger
Recording Secretary.....Dr. Henry F. Donner
Librarian.....Miss Helen M. Strohm

Professor Paul Annear of the Burrell Observatory, Baldwin-Wallace College, then lectured on "The Calendar Old and New." He demonstrated, with a planetarium, the fundamental time units upon which calendars are based, namely the day, month, and year. It was pointed out that a simple calendar is impossible because there are not an exact number of whole days in a year nor an exact number of whole lunar months in a year. The lunar calendar of ancient times was first described and its shortcomings pointed out. The Roman calendar was discussed, and the changes made in it by Julius Caesar in 45 B.C. and Pope Gregory in 1582 were explained. The World Calendar of 12 months was then presented and its advantages over our present calendar and the International Calendar of 13 months were pointed out. Some of the advantages are that any date in the year always occurs on the same day of the week each year; each quarter year has exactly the same number of days; each month has 26 work days, and the last day in the year is always an extra holiday; in leap years still another holiday occurs at the end of the first half of the year.

HENRY F. DONNER, *Secretary.*

3094 E. Overlook Rd., Cleveland Heights 18, Ohio.

The Cleveland Astronomical Society

The December meeting of the Cleveland Astronomical Society was held at the usual place in the Warner and Swasey Observatory of Case School of Applied Science. The writer lectured on "Astronomy in South Africa." The reasons for establishing astronomical observatories in that part of the world were pointed

out. It is far enough south for observing the southern stars. The extensive plateau of the interior, 4000 to 6000 feet above sea level, provides excellent seeing conditions and a large number of clear nights during the year.

The larger observatories now operating in South Africa were briefly described including the important work being done by each. They include the Royal Observatory near Cape Town, the Union Observatory at Johannesburg, the Yale southern station at Johannesburg, the Harvard southern station near Bloemfontein, the University of Michigan southern station at Bloemfontein, at which the writer was an observer for six years, and the Radcliffe Observatory at Pretoria.

At the close of the lecture a film was projected showing some of the observatories, native life, and scenes. It also included some pictures taken by the writer and his wife on their way home through Africa by automobile from Bloemfontein to Alexandria.

HENRY F. DONNER.

3094 E. Overlook Rd., Cleveland Hts. 18, Ohio, December 15, 1944.

Some Observations about an Observation

In order to eliminate as far as possible the human element and other sources of error from the clocking of occultations of stars by the moon, as many observations as could be made have been sought. Observations cannot be included in the discussions, however, unless they appear to meet certain standards of accuracy, which can only be obtained with good seeing and access to a good clock, the rate of which is known. It may be seldom, therefore, that occurrences of the phenomena at the bright limb of the moon may be included.

An exception to this is found when the occultation occurs during an eclipse of the moon. Here, however, the so-called bright limb is not bright and therefore this cannot be classed as a good exception.

There is another time when it may be found that an observation made at the bright limb will not offer the difficulties usually inherent in this phenomenon. The reference here is to those observation which may be made of the disappearance of bright stars in the daytime. The author cannot present evidence in the form of a timed observation in support of this contention, yet on the strength of what is to follow he would unhesitatingly recommend a trial of such observations by those who are interested in this phase of astronomy.

The fact that such observations present good possibilities came all unexpectedly at a recent occultation of Alpha Tauri. The predictions for the New Haven area included a reappearance of this object on September 2, 1942, at approximately 11:18 A.M., E.S.T. In order to make as good an observation of this event as could be, the author went to the telescope some twenty minutes before the object's disappearance, in order to locate the star in the center of the field and to see what sort of apparition it might be. The visibility was good. The image sharp and bright, and once seen could be easily relocated in the field. Its disappearance was watched with a half-hearted intent to clock it. Unfortunately, at the time of the event, the stop watch was not in hand. Having seen it however, it is my firm conviction that its clocking could have been superior to the timing of many reappearances, especially those of faint stars, and of those in which one is uncertain of the position angle.

The bright limb of the moon presented no difficulties in observing the star

right up to the instant of contact. Indeed it seemed pale by comparison with the star. It was interesting to note the apparent contrast in appearance of the two bodies. In the bright daylight our satellite presented a pale silvery white sheen, whereas the star appeared of a reddish hue. There was no merging of the light of the two objects, the star's disappearance being sharp and clean. This might not hold true with a fainter star.

Experience may show it to be impractical to undertake observing this phenomenon until the sun is well above the horizon, in order that the bright daylight may appear to dim the moon's light more than that of the star. Other factors to which one will have to give consideration of course will be the apparent distance of the two objects from the sun, as well as the light-gathering power of the instrument. The aforementioned observations were made with the 8½-inch Reed Memorial Telescope at Yale Observatory using a low-power ocular which would hold the entire moon well within the field.

The author's experience with other daylight observations has been limited. It has been his good fortune to witness two earlier occultations of Alpha Tauri in 1941, together with one of ξ^1 Ceti. These however were at the dark limb, and with the same instrument. It will be unfortunate if those who wish to try it do not have access to instruments of great enough light grasp. This is an important factor, shown when one of the foregoing events could not be witnessed by other men when they were using an excellent lens of some 5 inches diameter. However, in this case the day was very hazy, and the star presented a fuzzy appearance, somewhat comet-like in the Reed Telescope. But to those who attempt such observations under the right conditions, I believe a treat is in store, and with access to a good clock also, such observations can, I feel sure, add to the determining of the position of the moon.

J. J. NEALE.

New Haven, Connecticut.

Library of Congress Acquires Two Manuscripts by Albert Einstein

Two manuscripts by Professor Albert Einstein have just been deposited in the Library of Congress as a result of the Fourth War Bond Drive, it was announced recently by Archibald MacLeish, the Librarian of Congress.

One of these manuscripts is Professor Einstein's first essay on the theory of relativity with which his name is associated. The title of this manuscript is "Zur Elektrodynamik bewegter Körper" (On the Electrodynamics of Moving Bodies). It was first published in the *Annalen Der Physik*, at Leipzig, in 1905. Written by Einstein at the age of 26 while he was living in Berne, Switzerland, the paper, though not immediately recognized as such, represents the first step toward one of the greatest intellectual triumphs of modern times. Although the theory of relativity was not entirely new to scientific thought it was radically opposed to prevailing ideas regarding the static condition of matter, and many years were to pass and much experimentation was to be performed before it was generally accepted. As late as 15 years after the publication of this early paper Professor Einstein is reported to have warned the publishers of his book on the fully developed theory that only 12 persons in the world would be able to understand it.

The original manuscript of this early paper was discarded by Professor Einstein following its publication, but the present manuscript was written out by him in order to promote the sale of War Bonds through the activities of the

Book and Authors War Bond Committee. Under the auspices of this Committee it was auctioned to the highest bidder in War Bonds at a sale in Kansas City on February third last under the sponsorship of the Kansas City Woman's City Club and the Women's Division of the Kansas City War Finance Committee under the direction of Mrs. Charles M. Bush. The winning bidder for the manuscript was the Kansas City Life Insurance Company which bid $6,500,000 in War Bonds for it; and the manuscript is now presented by the Company to the Library of Congress.

The second Einstein manuscript which has been acquired by the Library of Congress embodies some of the mathematician's latest researches connected with the theory of relativity. This manuscript — Das Bi-Vektor Feld (Bivector Fields)—is addressed to the problem of finding a unified theory of gravitation. The results of this research were published by Professor Einstein in collaboration with Dr. V. Bargmann in the January 1944 issue of the *Annals of Mathematics*. This manuscript was also auctioned in the interest of War Bond sales under the auspices of the Book and Authors War Bond Committee at the Kansas City bond rally last February, and is presented to the Library by Mr. William T. Kemper, Jr., whose winning bid was $5,000,000 in war bonds.

Correction—In "Photographic determinations of stellar masses," POPULAR ASTRONOMY, **51**, the list of stellar masses on page 183 requires the following corrections:

Star no. 10 (ε Boo) Abs. vis. mag. read: +5.6 +7.6
Star no. 11 (ε UMa) Visual Magnitude read: 4.4 4.9
Abs. vis. mag. *B* read: +5.3

Observations at Midnight

(Meteors and Fireflies)

This is the harvest of heaven:
From the mysterious tree
Plummets the glittering fruit,
Luminous, far into space,

While in the lace of the leaves
Closer to earth and to me
Fireflies, in flickering flight,
Vie with the starry cascades.

Fireflies and meteors both
Share with the loveliest rose
That in one breath they are born,
Blossom, and wither away.

Transients of light, they enhance
Merely the night which endures.
Permanence, even through change,
Mirrors itself in the sky.

—GERHARD FRIEDRICH.

Guilford College, North Carolina.

POPULAR ASTRONOMY

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